GREAT LAKES RESEARCH

DEPARTMENT OF THE INTERIOR

MONOGRAPHS

OF THE

UNITED STATES GEOLOGICAL SURVEY

VOLUME LIII

WASHINGTON
GOVERNMENT PRINTING OFFICE
1915

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

THE

PLEISTOCENE OF INDIANA AND MICHIGAN

AND THE

HISTORY OF THE GREAT LAKES

BY

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AND

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WASHINGTON

GOVERNMENT PRINTING OFFICE

1915

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ABSTRACT OF VOLUME.

This monograph describes the glacial features and the great glacial lakes of a district in Indiana and Michigan lying between the areas covered by Monographs XXXVIII [1] and XLI.[2] The glacial features are treated mainly by Mr. Leverett, and the glacial lakes and their moraines by Mr. Taylor. The pre-Wisconsin glacial and interglacial formations are given attention, but the principal subject of discussion is the Wisconsin drift of the Saginaw lobe and the neighboring portions of the Lake Michigan and Huron-Erie lobes.

CHAPTER I. INTRODUCTION.—The drift sheets and intervals are outlined and the time divisions of stage and substage are explained. A bibliography of about 400 papers by nearly 150 different authors dealing with the region of the Great Lakes and the area southward to the Ohio is given.

CHAPTER II. PHYSICAL FEATURES.—The altitude and relief, the principal topographic features, the drift topography, the drainage systems, and the thickness of drift are briefly treated. The region is one of only moderate relief and the altitude nowhere reaches 2,000 feet. Small areas in the basins of Lakes Michigan and Huron are below sea level.

CHAPTER III. PRE-WISCONSIN DRIFT AND ASSOCIATED DEPOSITS.—The limits of glaciation in Indiana and Kentucky are outlined. The question of pre-Illinoian drift is discussed but no conclusion is reached. The topography, structure, and rock constituents, and other deposits of the pre-Wisconsin drift are briefly discussed. The striæ outside the Wisconsin drift are tabulated. The Sangamon soil and the post-Sangamon or main loess are briefly discussed.

CHAPTER IV. THE WISCONSIN DRIFT BORDER.—The edge of the Wisconsin drift and its characteristics are the main theme, but the existence of an earlier and a later Wisconsin drift and the grouping of moraines are treated briefly.

CHAPTER V. CORRELATIVES OF THE CHAMPAIGN MORAINIC SYSTEM.—The correlation of the Champaign moraines differs somewhat from that given in Monograph XXXVIII; moraines which were there said to override the Champaign system in western Indiana are now considered to be probable correlatives of that system.

CHAPTER VI. CORRELATIVES OF THE BLOOMINGTON MORAINIC SYSTEM.—The Bloomington morainic system of the Lake Michigan lobe is interpreted as finding its continuation across Indiana in a great belt of thick drift which runs eastward from Benton and Warren counties, with a slight bowing to the southward in central Indiana, and which enters Ohio from Randolph and Wayne counties. It is continued in Ohio as the "Main morainic system" discussed in Monograph XLI.

CHAPTER VII. THE SAGINAW LOBE.—The change from undifferentiated drift to definite lobes is interpreted as having been caused by a great recession of the border in the district east of the Lake Michigan lobe in northern Indiana and southern Michigan. Several moraines lying in this area of recession are discussed.

CHAPTER VIII. MORAINES OF THE NORTHERN LIMB OF THE HURON-ERIE LOBE IN INDIANA.—A complex morainic system is described as running northeastward from near Delphi, Ind., to the northeast corner of the State. It is interpreted as the correlative of several moraines that lie between it and the Lake Michigan lobe.

[1] Leverett, Frank, The Illinois glacial lobe: Mon. U. S. Geol. Survey, vol. 38, 1899.

[2] Leverett, Frank, Glacial formations and drainage features of the Erie and Ohio basins: Mon. U. S. Geol. Survey, vol. 41, 1902.

CHAPTER IX. MORAINIC SYSTEMS AT HEADS OF LAKE MICHIGAN AND SAGINAW BASINS.—The Kalamazoo morainic system of the Lake Michigan lobe, which was referred in Monograph XXXVIII to ice on its eastern side, is now interpreted as a product of the Lake Michigan lobe and distinct from the Valparaiso morainic system from South Bend, Ind., northeastward into Michigan though apparently merged with it in northwestern Indiana. The Lake Michigan-Saginaw interlobate tract, a prominent belt of interlobate moraines and included gravel plains, is described as running northward from Kalamazoo County to the vicinity of Cadillac. A strong morainic system of the Saginaw lobe, a continuation of the Kalamazoo morainic system, is described as running eastward from Barry County across Calhoun and Jackson counties to western Washtenaw County; its outer border shows great outwash aprons and lines of vigorous glacial drainage. The conspicuous moraines of the interlocking Saginaw and Huron-Erie lobes in southeastern Michigan and the included outwash plains and glacial drainage lines on the prominent peninsula known as the "thumb" of Michigan are described as far northeast as southern Lapeer County. The Charlotte morainic system of the Saginaw lobe is interpreted as a close successor of the Kalamazoo system and in places as being nearly merged with it. The Valparaiso morainic system of the Lake Michigan lobe is interpreted as a probably nearly full correlative of the Charlotte morainic system and a close successor of the Kalamazoo morainic system. It sweeps around the head of Lake Michigan in great strength.

CHAPTER X. LATER MORAINES OF THE LAKE MICHIGAN, SAGINAW, AND HURON-ERIE LOBES.—The Lake-Border morainic system of the Lake Michigan lobe, a series of slender moraines in the south part of the Lake Michigan basin between the Valparaiso morainic system and the shore of Lake Michigan and their continuation north and east over the highlands of the northern part of the southern peninsula of Michigan, is discussed. The reentrant district between the Lake Michigan and Saginaw lobes is declared to contain several narrow but well-defined moraines, which bow out to the northeast and become more convex in passing from older to younger. The moraines of the western limb of the Saginaw lobe, a massive morainic system northwest of Saginaw Bay, are described as separating into several distinct moraines southward, in the vicinity of Grand River. The moraines of the eastern limb of the Saginaw lobe, a series of slender moraines running from Grand River in Ionia County eastward and northward to Tuscola County, are described and the accompanying glacial drainages are discussed. The "thumb" of Michigan is interpreted as an interlobate area in which the slender moraines of the eastern limb of the Saginaw lobe become interlocked with moraines of the Huron-Erie lobe. Some of the later moraines of the Huron-Erie slope in southeastern Michigan are interpreted as having been laid down in glacial lake waters and to have very faint expression. The correlatives of the West Branch-Gladwin group of moraines in Ohio, New York, and Ontario and the Detroit interlobate moraine in southwestern Ontario are discussed very briefly.

CHAPTER XI. PORT HURON MORAINIC SYSTEM AND PROBABLE CORRELATIVES.—In the Huron and Saginaw basins the Port Huron morainic system is interpreted as marking a pronounced readvance of the ice border and is definitely correlated with glacial Lake Whittlesey; it is described as consisting of several closely associated ridges to which individual names have not been applied. The probable correlatives of the Port Huron system in Ontario and New York are briefly discussed. In the northern Michigan and northern Huron basins a morainic belt marking a distinct readvance of the ice in the northern portion of the Michigan basin is interpreted as the correlative of the Port Huron system; studies by Alden on the west side of Lake Michigan are declared to have brought out evidence of a readvance there. Other glacial features in the area between the Port Huron morainic system and the shores of Lakes Michigan and Huron are briefly discussed. Drumlins are conspicuous in the Grand Traverse region and occur in small areas east of Mullet Lake and near Alpena. Striæ harmonize in trend with the drumlins of Alpena County. Overridden lake (?) clays occur in the Grand Traverse region at elevations not greater than about 300 feet above Lake Michigan on the borders of deep and narrow lowlands largely occupied by lakes.

CHAPTER XII. OUTLINE OF GLACIAL AND POSTGLACIAL HISTORY OF THE GREAT LAKES REGION.—A brief outline of the Great Lakes history during and after the recession of the last ice sheet is given.

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CHAPTER XVI. GLACIAL LAKE ARKONA.—A lake that covered much of the area of Lake Maumee and Lake Saginaw and discharged into the Grand River outlet is described.

CHAPTER XVII. GLACIAL LAKE WHITTLESEY.—Lake Arkona is interpreted as having been so encroached on by a readvance of the ice border on the "Thumb" of Michigan that it was separated into two bodies of water, that to the east being called Lake Whittlesey and that to the west the Second Lake Saginaw; Lake Whittlesey discharged by the Ubly outlet to the Second Lake Saginaw and thence to the Grand River outlet and Lake Chicago.

CHAPTER XVIII. GLACIAL LAKE WAYNE.—The ice border is described as having receded sufficiently after its readvance to the main moraine of the Port Huron system to permit eastward discharge past Syracuse, N. Y., when the lake was drawn down to the level of the Wayne beach of southeastern Michigan.

CHAPTER XIX. GLACIAL LAKE WARREN.—The outlets of Lake Wayne past Syracuse are interpreted as having been covered by a readvance of the ice by which the glacial lake was raised high enough to discharge westward through the Grand River outlet, though at a level slightly below that of Lake Arkona. The name Lake Warren is applied to this expanded body of water.

CHAPTER XX. GLACIAL LAKE LUNDY AND THE TRANSITION TO LAKE ALGONQUIN.—With the recession of the ice border, discharge eastward is said to have been resumed, probably at first by way of the Syracuse channels. But later, by the opening of the Mohawk Valley through ice recession, the lake was drawn down to the level of the Niagara escarpment in the Erie basin and still lower in the Ontario basin. Niagara Falls then came into operation, and the Erie basin held a small lake which received the discharge from a glacial lake in the southern part of the Huron basin, the Early Lake Algonquin. Lake Chicago still persisted as an independent lake in the Michigan basin and Lake Duluth in the Superior basin.

CHAPTER XXI. GLACIAL LAKE ALGONQUIN.—By the opening of the low passage from the Michigan to the Huron basin Lake Chicago is interpreted as having become confluent with the Early Lake Algonquin. With further recession of the ice the Superior waters were also admitted and the great glacial Lake Algonquin resulted. By the uncovering of the Trent Valley in Ontario the discharge through the St. Clair Valley was abandoned, the Trent being the lower. Eventually differential uplift carried the Trent outlet above the level of the St. Clair, and the discharge returned to the St. Clair outlet and remained there during much of the time of rapid differential uplift. In connection with Lake Algonquin the contemporary lakes in the St. Clair and Erie basins are briefly treated.

CHAPTER XXII. THE NIPISSING GREAT LAKES.—The withdrawal of the ice is described as having opened the low passage to the Ottawa Valley. Eastward discharge along the south slope probably began while the ice was still present in the valley. The Nipissing Great Lakes stage dated from the complete opening of this valley and continued to the time when northward

uplift had brought the outlet up past the level of the St. Clair outlet and had caused a return to the discharge through the St. Clair Valley. There appears to have been a long two-outlet stage during which the beach known as the Nipissing was formed. The earlier beach, formed during the operation of the Ottawa outlet alone, became submerged and effaced by the rising waters everywhere in this lake area south of an isobase running through the head of the outlet.

CHAPTER XXIII. POST-NIPISSING GREAT LAKES AND SUMMARY OF GLACIAL AND NON-GLACIAL LAKES.—Beaches between the Nipissing and modern beaches, correlative post-Nipissing lakes in the Erie and Ontario basins, and the Champlain Sea are discussed. The problem of recent and progressing earth movement is considered briefly.

CHAPTER XXIV. POSTGLACIAL DEVELOPMENT OF CONNECTING RIVERS OF THE GREAT LAKES.—The history of St. Clair and Detroit rivers is given in some detail and that of the other rivers is briefly outlined.

CHAPTER XXV. DEFORMATION OF THE SHORE LINES.—The probable influence of ice attraction and the resilience following depression by ice weighting are discussed. Tectonic earth movements and negative eustatic and oceanic oscillatory movements are briefly considered.

CHAPTER XXVI. ECONOMIC RESOURCES.—Marl, peat, clay, and other materials of commercial value, underground water supplies, and the agricultural values of the soils of the region are briefly treated. References are made to detailed descriptions published elsewhere.

THE PLEISTOCENE OF INDIANA AND MICHIGAN AND THE HISTORY OF THE GREAT LAKES.

By FRANK LEVERETT and FRANK B. TAYLOR.

CHAPTER I.

INTRODUCTION.

By FRANK LEVERETT.

OUTLINE OF AREA AND SUBJECTS OF DISCUSSION.

The area discussed in this monograph lies between that discussed in Monograph XXXVIII (The Illinois glacial lobe) and that in Monograph XLI (The glacial formations and drainage features of the Erie and Ohio basins). It includes a considerable part of Indiana and all of the southern peninsula of Michigan. The monographs referred to contain a discussion of the entire exposed portion of the Illinoian drift in Indiana as well as in the neighboring States on the east and the west. The question of a pre-Illinoian drift in southern Indiana arose subsequently through studies in 1902 and is briefly treated in the present paper, but the Wisconsin drift, the concealed portions of the earlier drift sheets that underlie it, and the somewhat intricate lake history associated with and following the retreat of the ice are the main subjects of discussion.

FIELD WORK.

The Wisconsin and underlying drifts have been investigated chiefly by Mr. Leverett, and the lake history has been worked out largely by Mr. Taylor. During the investigations in Michigan, however, field conferences were frequent, so that each author is in a measure familiar with the main features and problems discussed by the other. Mr. Taylor's work in the neighboring portion of Canada, some results of which are presented, was carried on largely at private expense prior to his connection with this Survey. It was continued under the auspices of the Canadian Survey in 1908, 1909, 1911, and 1912.

The work of Mr. Leverett in Indiana and Michigan and that of Mr. Taylor in Michigan has been prosecuted chiefly under the direction of Prof. T. C. Chamberlin, who by his active interest, helpful suggestions, and occasional field visits has greatly stimulated the work and aided in the interpretation.

Dr. A. C. Lane, as State geologist, cooperated in the work in Michigan by helpful suggestions and contribution of valuable data which had come into his possession. He also, through an arrangement with the United States Geological Survey, contributed to the work from the State funds on the understanding that the State Survey should receive special reports on areas investigated by the aid of such funds. Through this arrangement Lapeer County was studied and described by Mr. Taylor in 1900, and Alcona County by Mr. Leverett in 1901. In addition to this the members of the State Survey have studied in some detail the Pleistocene features of Arenac, Bay, Huron, Iosco, Kent, Monroe, Saginaw, Sanilac, Tuscola, and Wayne counties with results that appear in the State reports. The work in these counties was so thorough that only a review was needed to connect it fully with the work in the bordering counties.

The annual reports of the Indiana Geological Survey contain results of somewhat detailed studies of the glacial deposits of certain counties and general observations on the drift of the

remainder of the State. Those by C. R. Dryer present exceptionally clear descriptions of the several moraines of the northeastern counties. These and other contributions by the Indiana Survey are reviewed in connection with the discussion of features on which they have bearing. The work of the Indiana Survey under the State geologist, W. S. Blatchley, has been directed toward the investigation of certain commercial products and, except in the report on road materials issued in 1906, has been little concerned with the glacial deposits.

As reference to townships is commonly made by number and range rather than by civil names, and as the numbering is connected with more than one meridian and base line, a brief explanation of the system is given.

Most of the townships of Indiana are numbered east and west from the second principal meridian, which runs through the State about 86° 28′ W. from Greenwich. A small triangular area in the southeast part of the State, however, is numbered west from the first principal meridian, which follows the State line of Indiana and Ohio. All the townships are numbered north and south from a base line that crosses the southern portion of the State 1 to 2 miles south of latitude 38° 30′ N. The State extends from T. 9 S. to T. 38 N. of this base line.

The townships of Michigan are numbered east and west from the Michigan meridian, which leads from Sault Ste. Marie south to the Ohio State line, and north and south from a base line that follows the parallel 42° 30′. Tho State extends from T. 8 S. to T. 39 N. in the southern peninsula and to T. 66 N. on Isle Royal in Lake Superior.

Each township has 36 sections numbered back and forth in tiers of six, the numbering beginning at the northeast and ending at the southeast corner of the township.

GLACIAL GATHERING GROUNDS AND ICE LOBES.

Studies by the Canadian Geological Survey have brought to light several large gathering grounds with smaller gathering grounds on their peripheries. The larger ice fields have been named from their places of occurrence, the Cordilleran, the Keewatin, the Patrician, and the Labrador. The Cordilleran field at its maximum occupied much of Canada west of the Rocky Mountains, but did not extend far south into the United States. The Keewatin field occupied central Canada, extended southward into the United States across Minnesota, the Dakotas, Iowa, and Nebraska into southeastern Kansas and central Missouri, and encroached on western Wisconsin and western Illinois. The Patrician[1] lay between Hudson Bay and Lake Superior and may have extended over Michigan. The Labrador ice field extended from the Labrador Peninsula southward and southwestward to the limits of glaciation in the district between the Atlantic seaboard and the Mississippi Valley; it encroached slightly on southeastern Iowa and caused a temporary displacement[2] of the part of Mississippi River touching eastern and southeastern Iowa. It is with the Labrador ice field that the present monograph is chiefly concerned, and with that part of it which covered the southern peninsula of Michigan and the glaciated portion of Indiana. As indicated later (pp. 64–65) the Patrician ice field may prove to have spread southeastward across Michigan into Indiana and Ohio before the Labrador ice field had entered this region.

The Labrador ice field developed two large lobes west of the Appalachians in its extension beyond the great basins through which it passed. The western lobe spread from the Lake Michigan basin over much of Illinois, forming the Illinois glacial lobe, the theme of Monograph XXXVIII. Its neighbor on the east extended through the Huron-Erie basin and on across western Ohio and eastern Indiana to the edge of Kentucky, forming another large glacial lobe. Between these two great lobes there is a conspicuous reentrant angle in the glacial boundary in southern Indiana. East of the eastern lobe there is a reentrant on the west slope of the Alleghenies which extends as far north as western New York. East of the Alleghenies there was less extensive lobing, though the border of the ice conformed markedly to the marginal topography.

[1] Tyrrell, J. B., Hudson Bay exploring expedition, 1912: Twenty-second Ann. Rept. Ontario Bur. Mines, pt. 1, 1913.
[2] Mon. U. S. Geol. Survey, vol. 38, 1899, p. 89.

The two great lobes mentioned were best developed at the time of maximum extent of the Labrador ice field, and this apparently occurred at the Illinoian stage of glaciation. At a later stage, the Wisconsin, there were two distinct lobes, the Green Bay and the Lake Michigan, in the western portion of the district covered by the Labrador ice field, and several lobes, the Saginaw, Maumee, East White, Miami, Scioto, and Grand River, within the limits of the eastern or Indiana-Ohio portion. These lobes blended somewhat at the culmination of Wisconsin glaciation.

The district considered in this monograph includes portions of the Illinois lobe and of the Indiana-Ohio lobe of the Illinoian ice invasion, and the entire Saginaw, Wabash, and East White lobes and the eastern portion of the Lake Michigan lobe of the Wisconsin ice invasion. This lobation, as long since suggested by Chamberlin,[1] resulted in great degree from the rapid movement and protrusion of the ice in tracts of low altitude. The overlapping of the Labrador ice on ground previously occupied by the western ice indicates a marked change, the cause for which is not yet clearly understood, in the conditions for ice accumulation in the two gathering grounds.

GLACIAL SUCCESSION.

The occurrence of several distinct sheets of drift separated by soils and iron-stained, leached, or weathered surfaces has been recognized for some years by those familiar with the glacial deposits of North America. The matter has been discussed by the present writer at some length in each of the two monographs already published,[2] and for this reason only a brief outline is here presented. In order of age from older to younger the following drift sheets and intervals appear:

OLDEST RECOGNIZED DRIFT.

In New Jersey and eastern Pennsylvania an old drift, named by Chamberlin and Salisbury[3] the Jerseyan and considered by them as old as any yet found in America, is preserved chiefly in places where erosion has been at a minimum and over much of the area is now present only in small detached patches. It is very deeply weathered, a fact that corroborates the testimony of erosion as to its great age.

In northwestern Pennsylvania on the borders of the Allegheny Valley an old drift, preserved in the recesses of bluffs and in scanty deposits on uplands, seems scarcely so old as the Jerseyan and yet may prove to be its correlative.

West of the Mississippi an extensive sheet of old drift pertaining to the Keewatin ice field is covered by the Kansan drift and thus has received the name pre-Kansan. It lies also beneath the Aftonian buried soil and weathered zone and for that reason is frequently referred to as the sub-Aftonian drift. Recently Prof. Shimek, of the Iowa Geological Survey, traced it westward into Nebraska and gave it an additional name, the Nebraskan. This drift is separated from the Kansan by the long interglacial Aftonian stage and is much the older, old though the Kansan is, and it is thought to be a possible if not a probable correlative of the Jerseyan drift. It is still, however, not definitely settled that the Labrador and Keewatin ice fields reached the limits of these their oldest drift sheets contemporaneously.

G. M. Dawson[4] applied the term Albertan to a deposit of mountain drift and gravel in the Province of Alberta in Canada and in neighboring parts of Montana which he considered to be derived from the Rocky Mountain ice. Later investigations by Calhoun[5] raising doubts as to the glacial origin of this gravel have been negatived by W. C. Alden, who in 1911 and 1912 discovered glaciated pebbles and distinct evidence of glacial origin.[6] The aspect of the deposit is very aged and at present it is considered an early glacial deposit.

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[1] Trans. Wisconsin Acad. Sci., vol. 4, 1878, pp. 201–234; Third Ann. Rept. U. S. Geol. Survey, 1883, pp. 291–402.

[2] The Illinois glacial lobe: Mon. U. S. Geol. Survey, vol. 38, 1899; Glacial formations and drainage features of the Erie and Ohio basins: Mon. U. S. Geol. Survey, vol. 41, 1902.

[3] Geology, vol. 3, 1904, pp. 383–384.

[4] Glacial deposits of southwestern Alberta: Bull. Geol. Soc. America, vol. 7, 1895, pp. 31–66.

[5] Calhoun, F. H. H., The Montana lobe of the Keewatin ice sheet: Prof. Paper U. S. Geol. Survey No. 50, 1906, pp. 42–52.

[6] Pre-Wisconsin glacial drift in the region of Glacier National Park: Bull. Geol. Soc. America, vol. 23, 1912, pp. 687–708.

It is an open question whether the oldest drift is represented in the southern peninsula of Michigan and in Indiana, the area covered by the present report. The presence of copper nuggets in the drift over the entire southern peninsula and southeastward into central Ohio seems to call for an ice movement from the Lake Superior region across the southern peninsula and probably through the Huron basin to the limits reached by the nuggets. The ice movement in the Illinoian and Wisconsin stages of glaciation seems to have been such that copper could not have been carried into Ohio from the Lake Superior region. It appears, therefore, that this transportation was effected in Kansan time or earlier, at a time when the Labrador glaciation was relatively weak.

FIRST OR AFTONIAN INTERGLACIAL STAGE.

Evidence of the Aftonian interglacial stage is clearest in the region west of the Mississippi. It was noted about 1888 by Chamberlin and McGee near Afton, Iowa, and was made by Chamberlin [1] the type locality for the interval. Bain [2] subsequently brought out additional data concerning it. Calvin [3] and Shimek [4] have recently presented results of studies in western Iowa which give a clearer understanding of this deglaciation interval and which make it appear that a warm temperate fauna had possession of that region between the pre-Kansan and Kansan stages of glaciation.

KANSAN DRIFT.

The Kansan drift, which in the Mississippi Valley overlies the pre-Kansan drift and which is thought to extend beyond its limits in Kansas and Missouri, was first clearly brought to notice in its proper relations by Calvin and his associates on the Iowa Geological Survey and is discussed in the several volumes of that survey which deal with counties of eastern, southern, and western Iowa. It is an open question whether this drift is represented in southern Michigan and Indiana. Possibly the copper noted above was brought in at this instead of pre-Kansan time. As a surface sheet the Kansan is displayed in the States west of the Mississippi, though even there it is covered by loess. It is also overridden to some extent near the Mississippi by the Illinoian drift.

SECOND OR YARMOUTH INTERGLACIAL STAGE.

SOIL AND WEATHERED ZONE.

The first part of the second interglacial stage embraces a long interval, during which the surface of the Kansan drift was weathered and the soil and peat beds which separate the Kansan from the overlapping Illinoian drift were developed. The region of overlap is along the borders of the Mississippi south of the driftless area, in southeastern Iowa and western Illinois. The locality where evidence of this interval was first clearly recognized is at Yarmouth (near Burlington), Iowa, where the overlap is by the drift of the Labrador ice field upon that of the Keewatin ice field.

LOESS.

Between the Yarmouth interglacial soil and weathered drift and the overlying Illinoian drift, and therefore of pre-Illinoian age, there lies in places a deposit of loess, which is best displayed in the region of overlap of the Illinoian on the Kansan drift, and which seems to have resulted from a less humid climate than that under which the peat was formed.

ILLINOIAN AND IOWAN DRIFTS.

The Illinoian appears to be the most extensive drift sheet of the Labrador ice field. It is thought to extend to the glacial boundary in Indiana as well as in neighboring parts of Ohio, Kentucky, and Illinois. The name Illinoian is applied because of the wide exposure of this

[1] Classification of American glacial deposits: Jour. Geology, vol. 3, 1895, p. 272.
[2] Bain, H. F., Proc. Iowa Acad. Sci., vol. 5, 1898, pp. 86-101.
[3] Calvin, Samuel, Proc. Davenport Acad. Sci., vol. 10, 1907, pp. 18-31, 7 pls.; Bull. Geol. Soc. America, vol. 20, 1909, pp. 136-139, 341-356.
[4] Shimek, Bohumil, Bull. Geol. Soc. America, vol. 20, 1909, pp. 399-408, Pls. XXX-XXXVII; vol. 21, 1910, pp. 119-140.

drift sheet in the State of Illinois. In its peripheral portion it shows complexity that is not as yet fully understood. Loess is interbedded to some extent with till, and silt thought to be of aqueous deposition fills many of the valleys. The loess may prove to be derived from pre-Illinoian loess gathered by the wind from districts outside and redeposited in such manner as to become interbedded with Illinoian till.

The presence or extent of the Illinoian drift in the Keewatin field remains to be determined. The only drift yet reported in that region to occur between the Kansan and Wisconsin drift is termed Iowan. That drift, however, has been placed by the Iowa Geological Survey either as a correlative or a close forerunner of the main or post-Sangamon loess.

THIRD OR SANGAMON INTERGLACIAL STAGE.

A well-defined interval of soil forming and leaching on the surface of the Illinoian drift came in prior to the deposition of the overlying loess. The soil formed is named from the Sangamon River basin in Illinois, where its occurrence was brought to notice by Worthen many years ago in reports of the State Survey. The soil and the weathering are well developed in Indiana and Ohio as well as in Illinois.

POST-SANGAMON OR MAIN LOESS (IOWAN?).

The chief loess deposit east of Mississippi River overlies the Sangamon soil. West of that stream it extends beyond the limits of the Illinoian drift and rests either on a soil developed on the surface of the Kansan drift or on an earlier loess (pre-Illinoian) that has a patchy preservation in that region. As noted above, it has been considered a somewhat close correlative or possibly close successor of the Iowan drift. So far as the region under discussion is concerned no Iowan drift has been recognized.

PEORIAN OR POSTLOESSIAL SOIL AND WEATHERED ZONE.

The post-Sangamon loess and its associated silts suffered some weathering before the Wisconsin ice invasion. Exposures of the loess beneath the Wisconsin drift near Peoria, Ill., in which the upper part of the loess is more weathered than the lower, have led to the use of the name Peorian to represent the pre-Wisconsin weathering, erosion, and general alteration of the loess.

WISCONSIN DRIFT.

LOBATION OF THE BORDER.

At the culmination of the last or Wisconsin ice invasion the outline of the border differed considerably from that at the culmination of the Illinoian invasion, falling short in places by more than 100 miles and extending beyond in other places. The portion in Illinois fell short the most. From Illinois eastward to central Ohio the borders gradually approach each other, and beyond central Ohio the Wisconsin border overlaps the Illinoian and in places extends beyond the Jerseyan? drift. In the Green Bay lobe of Wisconsin the Wisconsin drift overlaps the border of the Illinoian and encroaches on what had been driftless area in the Illinoian stage of glaciation.

The drift border of the Wisconsin invasion is more lobed than that of the Illinoian, especially in Indiana and Ohio, where it includes the deposits of the East White, Miami, Scioto, and Grand River lobes. In Illinois the Wisconsin had but one pronounced lobe, the Lake Michigan, whose outline was rudely concentric with that of the Illinoian drift border. This lobe was an extension from the Lake Michigan basin. It formed, in the course of its withdrawal from Illinois, a succession of bulky but rather smooth morainic ridges, which extend into western Indiana for a few miles to the head of the reentrant between it and the portion of the Labrador ice field that passed through the Huron and Erie basins. This reentrant is a few miles farther west than the great reentrant between the Illinois and the Huron-Erie lobes of the Illinoian stage (see Pl. V, p. 62), the latter being in south-central rather than southwestern Indiana.

The moraines of the Huron-Erie lobe east of the reentrant differ in type from those formed by the Lake Michigan lobe on the west. They lack the strong bold ridges of the moraines of the Lake Michigan lobe and vary greatly in expression from place to place. A portion of pronounced morainic type with closely aggregated bowlder-strewn hummocks inclosing numerous basins may be followed within a few miles by a stretch where the knolls or hummocks are very scattered, and the whole aspect is vague. In places bowldery strips tie together well-defined sections, but in some places even these fail, leaving the ice border without definite trace. The bowldery belts also take singular turns away from the moraines, some of them in fact lying more nearly coincident with the direction of ice movement than with the trend of the ice border. This lack of continuity characterizes all the moraines of Wisconsin drift in Indiana outside the Mississinawa morainic system of the Huron-Erie lobe.[1] That system and later ones in the series formed by the Huron-Erie lobe, though less bulky than the moraines of the Lake Michigan lobe, are well-defined ridges that control the drainage and admit of easy tracing.

EARLIER AND LATER WISCONSIN.

The contrast between the features of the Lake Michigan lobe and those of the Huron-Erie lobe and especially the contrast in topography were at first thought to show a difference in age, the sharp hummocky shapes east of the reentrant angle being thought to be fresher than the gentle undulations of the drift of the Lake Michigan lobe west of it. This idea has been widely introduced into the literature and on it is based the division into earlier and later Wisconsin, the moraines of the Lake Michigan lobe, from the Shelbyville to the Marseilles, having been placed in the earlier Wisconsin, and nearly all those of the Huron-Erie lobe of the ice field having been classed as later Wisconsin.

The argument drawn from the differences in contour was supported by an overlapping upon the eastern ends of the moraines of the Lake Michigan lobe by bowldery strips that have a trend in harmony with the moraines of the Huron-Erie lobe and that contain rocks characteristic of the Huron-Erie ice. Thus the four moraines in the Bloomington morainic system of the Lake Michigan lobe, which trend west-southwest and east-northeast near their eastern ends, are crossed about at right angles by a bowldery belt which runs north-northwest and south-southeast from eastern Iroquois County, Ill., across western Benton and Warren counties, Ind., to the Wabash Valley at Attica, and which to the south of the Wabash is associated with a moraine of the Huron-Erie lobe. It was thought that the bowlder belt north of Attica, like that south of the Wabash Valley, was formed at the border of the Huron-Erie ice and that its incursion into the region occupied by moraines and till plains of the Lake Michigan lobe necessitated the earlier disappearance of the Lake Michigan lobe. In the vicinity of the bowldery strip certain deposits of till, among which is the gray till on Stone Creek near Williamsport, appear to be a product of movement from the east.

Another feature which was thought to support the division into earlier and later Wisconsin is the cross striation in western Indiana; one set of striæ bears southward as if formed by the Lake Michigan lobe, and a later set bears westward as if formed by the Huron-Erie ice movement. It now appears, however, that the southward-pointing striæ were produced at the Illinoian rather than at the Wisconsin stage, for they occur farther east than the Lake Michigan glacier is known to have extended in the Wisconsin stage and farther south than the Wisconsin drift limit. For this reason they can not be used for differentiating the so-called earlier and later Wisconsin movements.

The early hypothesis implies great discordance in glaciation in the Lake Michigan and Huron-Erie portions of the Labrador ice field. Under it not only must the Lake Michigan ice have melted back about to the limits of the Lake Michigan basin, and have developed several very bulky moraines in the course of its recession while the Huron-Erie ice held nearly its maximum position, but the Lake Michigan ice border must afterward have maintained its position just outside the limits of the Lake Michigan basin and have formed

[1] Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 494-509.

only one prominent morainic system (the Valparaiso) while the Huron-Erie ice border was receding across Indiana and Ohio about to the limits of the Erie basin and developing several moraines in the course of its retreat. It would seem more natural for the two parts of the Labrador ice field to have had a similar mode of recession instead of this discordance, and it now seems likely that the features noted are such as might be developed where ice currents from different directions were meeting on common ground, but where neither dominated strongly over the other or persisted after the other had withdrawn or melted away.

The bowlder belt, though reaching 5 to 10 miles beyond the line of junction marked by the eastern termini of the ridges of the Bloomington morainic system makes really a very slight overlap in comparison with the great area of the two divisions of the Labrador ice field, and there seems no great difficulty in explaining it on the basis of slight encroachment of the eastern movement into territory which had been occupied by the Lake Michigan glacier. This overlapping may perhaps have been merely in the surface portion of the ice sheet, and thus may not have affected the basal portion. The bowlder deposition may have begun at the south at the time when the oldest of the four moraines of the Bloomington system was forming and have extended northward with the recession of the ice border along the junction of the Lake Michigan and Huron-Erie ice and not have been completed until the last of the ridges of the Bloomington system had been formed. In other words, the bowlder belt would mark a line of recession instead of the trend of an ice border.

After the development of the Bloomington morainic system there seems to have been rapid recession along the junction of the Lake Michigan and Huron-Erie lobes across the Kankakee basin and on northeastward into southern Michigan as far as the Kalamazoo Valley east of the city of Kalamazoo. Along this line are numerous bowldery patches and morainic areas that appear to pertain to an interlobate moraine, and extensive outwash aprons that make it possible to work out in a rude way the progress of the recession.

As the terms earlier and later Wisconsin were introduced under the view that there had been a great shifting and readjustment of the ice currents the present distrust of the correctness of that view necessitates the suspension of the use of the terms so long as the distrust continues. It may be necessary to revive the terms if further investigation discloses a clearly defined basis. It is probable that the outer moraine of the Green Bay lobe and, indeed, much of the Wisconsin border in Wisconsin, Minnesota, Iowa, and the Dakotas may be younger than the Shelbyville morainic system of the Illinois lobe. If such should prove to be the case, it might be convenient to refer to the older portion of the Wisconsin border as earlier Wisconsin and to the younger portion as later Wisconsin. This matter, however, is not important in the area covered by the present monograph and may be left with this passing suggestion.

Attention was directed in Monograph XLI (pp. 352–353) to certain broad, shallow valleys cut in outwash gravels of the earlier part of the Wisconsin stage in the reentrants between the East White and Miami lobes and the Miami and Scioto lobes. The morainic ridges of the main system cross the beds of these channels in such way as to show that they were later than the channeling. The cuts are shallow, being generally only 25 to 50 feet deep, but in places reach a width of 2 miles or more. The amount of work done seemed to the writer at the time Monograph XLI was written to require a considerable time, and it was referred to the interval between the earlier and later Wisconsin drift. Subsequent studies in the southern peninsula of Michigan, however, have brought to light other instances of large erosion in reentrant angles between ice lobes or in places where glacial drainage was greatly concentrated, and this erosion seems to have occurred in the ordinary recession of the ice sheet without the lapse of a long interval such as was postulated in eastern Indiana and western Ohio. The writer is not at present disposed, therefore, to allow so much time as he formerly did for the erosion of these channels, for in both of them there must have been great concentration of glacial drainage.

RETREATS AND READVANCES OF THE ICE.

The Wisconsin drift, as displayed in Illinois, Indiana, and Michigan, has several complex systems of moraines marking either halts or readvances of the ice border, between which are nearly plane-surfaced tracts over which the ice border probably retreated somewhat rapidly. In connection with the retreat of the ice sheet into and beyond the basins of the Great Lakes, large glacial lakes were developed, the drainage of which differed widely from the present system of drainage, being chiefly to the Mississippi and the Gulf of Mexico.

GROUPING OF THE MORAINES.

The moraines of the Wisconsin stage are more or less concentrated in groups. (See Pl. XXXII, in pocket, and table opposite this page.) Several moraines, closely crowded together, adjoin a few that are more widely spaced, and these in turn are succeeded by another closely crowded group, and then by others more widely spaced. Thus in the Illinois district the Shelbyville morainic system, formed at the culmination of the Wisconsin stage of glaciation, consists of three ridges where most deployed and of one or two where more closely crowded. North of this comes the Cerro Gordo moraine, the latest moraine of the Shelbyville system, and three weak ridges classed as the Champaign morainic system, which are distinct for most of their length, but which merge at the west into a single ridge. Thus of seven ridges three are closely combined into the great Shelbyville system, and four, whose aggregate bulk is less than that of the Shelbyville system, are spread over a space several times as great. These weaker ridges are succeeded to the north by four bulky, closely associated ridges known as the Bloomington morainic system, which in turn is succeeded in eastern Illinois by two widely spaced moraines, the Marseilles morainic system and the Minooka moraine, and in northwestern Indiana and southern Michigan by others known as the Maxinkuckee, the Bremen, the New Paris, the Middlebury, the Lagrange, the Sturgis, and the Tekonsha, which can be compared with the Cerro Gordo moraine and the Champaign system, though they are as a whole somewhat more bulky. Next comes another series of moraines, which comprises the Kalamazoo and Valparaiso morainic systems of the Lake Michigan basin, and the Mississinawa morainic system and perhaps three or four later moraines of the Huron-Erie basin. Connecting these is a great series of moraines at the end of the Saginaw lobe, whose principal members pass through Jackson and Charlotte and which is comparable to the Bloomington and Shelbyville systems. It is followed by a series of weaker and more widely spaced moraines which extend back, in the Saginaw and Huron basins, to the Port Huron morainic system of closely aggregated ridges. This last, in turn, is followed by other wider-spaced ridges.

The moraines of the Wisconsin drift are so numerous and in places are so intricately combined that in this paper it is found advantageous to consider them in groups rather than to attempt complete correlation of each moraine across the entire region discussed. This method has nearly all the advantages of individual tracing without involving questionable correlations. It is also much simpler for the reader to follow.

The first two groups of moraines, as noted above, include those formed in the adjustment of the shrinking ice sheet to the basins that held the Lake Michigan, Saginaw, and Huron-Erie lobes. With their intermorainic tracts they include an area reaching from south of Kankakee River in western Indiana to south of Mississinawa River in eastern Indiana and extending northward into Michigan to the vicinity of Kalamazoo and Battle Creek.

The third group of moraines embraces the Kalamazoo and Valparaiso morainic systems of the Lake Michigan lobe, the Kalamazoo and Charlotte systems of the Saginaw lobe, the Mississinawa, Salamonie, Wabash, and Fort Wayne moraines of the Huron-Erie lobe, and the interlobate belts between the Lake Michigan and Saginaw lobes and between the Saginaw and Huron-Erie lobes. In this group all the bulky moraines of the southern half of the southern peninsula of Michigan are included.

The fourth group of moraines embraces the Lake Border morainic system of the Lake Michigan lobe, a series of weak moraines in the Saginaw basin and the moraines between the

Illinois lobe.	Indiana reentrant, [cut off] White lo[cut off]		Huron-Erie lobe (successor to Miami and Scioto lobes and part of Indiana reentrant).
		id).	Port Huron morainic system. Main moraine.
		of the "thumb."	
		ridges. idges. raine. ne .... raine. oraine. noraine. oraine............ (St. John?) mo- raine. moraine.......... ') moraine........	Grosse Isle moraine. Bowlder belts of Monroe and Wayne counties. Transverse ridges. Adair moraine. Emmett moraine. } In Canada merge into Detroit interlobate Mount Clemens moraine. } moraine. Berville moraine. Goodland moraine. } Formerly called Toledo moraine. Imlay moraine. } (Grosse Isle to Imlay:) Water-laid. Birmingham moraine and Michigan portion of water-laid Detroit interlobate moraine. (Contemporaneous.) Defiance moraine, double in part of southeastern Michigan, the other member being the "middle moraine" of the Ann Arbor folio and the "Northville moraine" of Sherzer's Wayne County report.
			Minor ridges, including Bluffton and Rawson moraines. Fort Wayne moraine. Wabash moraine. Salamonie moraine.
			Mississinawa morainic system.
			Undifferentiated in northern Indiana; weak undulating strips in central Indiana, including the Union City moraine.
Minooka moraine.			
Marseilles morainic system ("Marseilles-Iroquois moraine" of earlier reports).	Marseilles morainic [cut off] seilles-Iroquois mo[cut off] reports).		
Bloomington morainic system. (Comprises one to four large unnamed ridges and several minor ridges, such as Marengo ridge, Chatsworth-Cayuga ridge, and Fern or Grand ridge.)	Bloomington morain[cut off] named ridges, [cut off] Gilboa ridge, [cut off] bowlder belt, Ston[cut off] belt, and High Ga[cut off]		
Champaign morainic system. { Inner ridge. Middle ridge. Outer ridge.	Champaign morainic [cut off]		
Shelbyville morainic system. { Cerro Gordo moraine. Main moraine (in places with double or treble crest).	Shelbyville moraini[cut off] named ridges, inc[cut off] Hartsville bowlde[cut off] dulating strip, St.[cut off] dulating strip, and White lobe.)		

34407°—15. (To face page 30.)

Huron and Erie basins back to the Port Huron morainic system. The moraines of this group are relatively weak except in the vicinity of the junction of the Saginaw and Lake Michigan lobes and between the Saginaw and Huron-Erie lobes.

The fifth group embraces a series of moraines which is clearly separable from earlier moraines on the western side of the Lake Michigan basin and in part of its course on the eastern side, and which appears to be correlated with the Port Huron system of moraines in the Huron basin. In Wisconsin it includes the series of red-clay moraines which are found from Milwaukee northward. On the Michigan side its correlatives embrace the Whitehall moraine, which is traceable northward from the vicinity of Muskegon, and some later moraines which appear on the borders of Lake Michigan farther north. Of these last, two ridges that lead north from near Manistee, Mich., seem to correlate with ridges on the Wisconsin side near Two Rivers; they were formed subsequent to the development of the Glenwood and Calumet beaches of Lake Chicago and the series of Arkona beaches in the Huron-Erie basin, for they override the northern ends of these beaches and thus show a readvance of the ice. On retreating from this morainic system the ice melted away from the Lake Michigan and Huron basins.

Later groups exist in the region south of Lake Superior and probably still others north of the lake in Canada, but these lie outside the region embraced in the present discussion and they have as yet been but partly worked out.

EVIDENCE OF READVANCE OF THE ICE.

Readvance of the ice along at least a portion of the length of these bulky morainic systems is more or less evident. At its western end, from Peoria, Ill., northward, the Bloomington system overrides not only the weak moraines of the Champaign system but even extends into the ground occupied by the Shelbyville system and makes it impossible to differentiate the two. The readvance in eastern Illinois and farther east appears to have been less pronounced, the Kalamazoo and Valparaiso systems being separated from the Bloomington by fewer moraines in Illinois than in northwestern Indiana. In the Port Huron morainic system the evidence of readvance is very clear, especially on the peninsula or "thumb" of Michigan, between the southern part of Lake Huron and Saginaw Bay, where, as shown by Mr. Taylor (p. 362), the readvance caused a rise of the waters of a glacial lake outside the ice.

The supposed correlatives of the Port Huron morainic system in the Lake Michigan basin are more widely spaced than in the Huron basin; an outer member on the Wisconsin side contains a red drift carried over a drift of lighter color, as noted by Chamberlin and Alden, and later members on each side of the lake override the two higher beaches of the glacial lake Chicago, which occupied the south part of the Lake Michigan basin.

CHRONOLOGY OF THE WISCONSIN ICE SHEET.

STAGE AND SUBSTAGE.

The great morainic systems noted can scarcely be classed as recessional moraines. Instead they appear to have been formed at the culmination of a readvance of more or less consequence. These readvances are of a rank subordinate to that of glacial stages such as the Wisconsin, the Illinoian, and the Kansan and seem to require a distinct designation. They appear to be of similar rank to the readvances in the Alps that produced the Bühl, the Gschnitz, and the Daum moraines and to represent perhaps similar divisions of the glacial stage. The term "stadium," which is used in the Alps region for the part of the glacial stage falling between two marked readvances of the ice, marks an areal oscillation rather than a time interval. It seems preferable therefore to use the term "substage." Thus the Bloomington substage covers the time of deposition of the Bloomington morainic system and of all the later moraines back to the Kalamazoo-Mississinawa morainic system, including any that have been overridden by the latter system. The Kalamazoo or Mississinawa substage covers the time of deposition of the moraines of the contemporaneous Kalamazoo and Mississinawa systems and of all moraines back to or overridden by the Port Huron morainic system.

Certain features seem to indicate that the substages may eventually need subdivision, but this will not be attempted at this time. Thus certain moraines within the group embraced in a given substage show a slight forward movement into territory that had been vacated by the ice sheet; also a crowding together of subsidiary ridges in certain complex moraines is followed by wider spacing. This is notable in part of the St. Johns moraine of the Saginaw basin and is not uncommon in other moraines.

CALCULATION OF TIME.

The calculation of time involved in the disappearance of the ice sheet at the last stage of glaciation may be worked out on this basis. If the time required for the development of a morainic ridge or of a subsidiary ridge can be satisfactorily determined a rude estimate may be made of the entire time required for the retreat of the ice from the southernmost to the northernmost of the moraines that have been mapped.

The calculation must be based on areas where the moraines show the best development and on moraines which show the fullest development of subsidiary ridges. Account must be taken not only of the visible subsidiary ridges in the moraine which displays them best but also of ridges that were possibly overridden in the course of a readvance to the culminating position. Similarly, it is insufficient to count the visible moraines of a substage; calculations must also be made for moraines that were overridden in the next succeeding substage. Calculations based on overridden material are necessarily less definite than those based on visible features, and must be given correspondingly less weight.

RETARDATION OF MOVEMENT IN THE SAGINAW LOBE.

The area covered by this monograph is probably less suitable for demonstrating the oscillatory movement of the ice border and the periodicity of the expansions and contractions of the ice than are districts in which the ice had greater freedom for wide deployment. The area was one of conflicting ice movements, the Saginaw lobe being crowded on each side by neighboring lobes. Studies in the field have brought to light evidence (see p. 128) which points to the relative stagnation of the movement or to a steady decrease in the Saginaw lobe in sharp contrast with the oscillations of the border displayed by the Lake Michigan lobe on the west and the Huron-Erie lobe on the east.

The oscillations in the Lake Michigan lobe are also somewhat peculiar, for they show a tendency to a westward shifting of the axial movement. Thus the axis of movement at the time the Shelbyville morainic system was being formed was along a line pointing toward Shelbyville, Ill., from the southern end of the Lake Michigan basin, whereas at the time the Bloomington morainic system was being developed the axial line was directed more nearly toward Peoria, Ill. Still later, the movement shifted so much farther to the west that in southern Wisconsin the moraines override those of the Bloomington system. It is probable that this shifting resulted from the great accumulations of drift on the eastern side of the Lake Michigan basin, especially in Oceana and Mason counties, where the trend of the east shore changes from southwestward to southward. The eastern side of the Lake Michigan lobe had thus less freedom for deployment than the western, and the ice tended to hold its position on the east while it was advancing on the west.

The conflicting movements just mentioned may have served to prevent obliteration of records by burial of the glacial features such as occur in regions of oscillating ice border, and in this way the Saginaw and neighboring districts may be of exceptional value in working out the full series of moraines. As will be shown later (p. 123), the number of moraines preserved in this region is certainly greater than in the region of freer movement to the west.

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BORDEN, W. W., Reports upon counties of southern Indiana. Clark and Floyd counties: Fifth Ann. Rept. Geol. Survey Indiana, 1873, pp. 178–179. Scott and Jefferson counties, Sixth Rept., 1873, pp. 115–118. Jennings and Ripley counties, Seventh Rept., 1875, pp. 171–174, 178, 195–196.
Notes the occurrence of small quantities of gold and much buried timber in the glacial deposits and buried soils under the drift.

BOWMAN, AMOS, Testimony of Ottawa clays and gravels to the expansion of the Gulf of St. Lawrence and Canadian lakes within the human period: Ottawa Naturalist, vol. 1, 1888, pp. 149–161.
Gives results of personal observations and summarizes work of other observers.

Bowman, Isaiah, A typical case of stream capture in Michigan: Jour. Geology, vol. 12, 1904, pp. 326–334.

Discusses the capture of a very small tributary of Huron River near Ypsilanti by the widening of the Huron Valley until it cut into the path of the tributary.

——— Flowing wells and municipal water supplies of Clinton, Eaton, Barry, Ionia, Montcalm, Ottawa, and northern Allegan counties, Mich.: Water-Supply Paper U. S. Geol. Survey No. 182, 1906, pp. 155–169, 225–226.

Bownocker, J. A., A deep preglacial channel in western Ohio and eastern Indiana: Am. Geologist, vol. 23, 1899, pp. 178–182, with map.

Traces a deep channel by borings from Shelby County, Ohio, to Blackford County, Ind.

Bradley, F. H., Geology of Vermilion County, Ind.: First Ann. Rept. Geol. Survey Indiana, 1869, pp. 138–141.

Notes buried soil and distinct sheets of glacial drift.

——— Grundy, Will, Kankakee, Iroquois, Vermilion, Edgar, Ford, and Champaign counties, Ill.: Illinois Geol. Survey, vol. 4, 1870, pp. 190–194, 205–209, 222–230, 236–238, 241–244, 266, 272–274.

Notes buried soil and distinct drift sheets in several counties.

Breeze, F. J., The valley of the lower Tippecanoe River: Proc. Indiana Acad. Sci., 1901, pp. 215–216.

Presents map and discusses width of valley and of stream.

Bretz, J. H., Glacial features of Genesee County [Mich.]: The Schoolmaster (an educational journal published monthly at Saginaw, Mich.), Feb. and Mar., 1907, pp. 482–487 and 530–539.

Gives a general description of the glacial and lake formations of Genesee County and a map covering most of the county. Discusses the topography and gives a clear account of the recession of the ice sheet and the development of moraines, till plains, eskers, glacial drainage channels, etc., the succeeding lake stages with beaches, deltas, etc., and the relation of all of these features to the present drainage.

Brown, R. T., General sketch of geology of Indiana: Third Rept. Board Agri., 1853, pp. 299–322.

——— Reports upon counties in Indiana: Fountain County drift and buried channels: Eleventh Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1881, pp. 91–94; Marion County, glacial deposits, terraces, buried channels, postglacial drainage, well sections, etc.: Twelfth Rept., 1882, pp. 81–96; Morgan County, glacial deposits (including gold and diamonds), drainage features, etc.: Thirteenth Rept., 1883, pp. 79–83; Hamilton and Madison counties, glacial deposits and postglacial drainage: Fourteenth Rept., 1884, pp. 22–26, 32–37; Hancock County, glacial features, drainage, and soils: Fifteenth Rept., 1886, pp. 187–197.

States that buried soils occur between drift sheets in several of these counties.

Burt, W. A., In S. Ex. Doc. No. 1, 31st Cong., 1st sess., 1849, pt. 3, p. 820.

Notes that Lake Superior was formerly much larger than now.

Cable, E. J., Road materials of a portion of central Indiana: Thirtieth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1905, pp. 656–674, 681–755.

The occurrence of gravel deposits in workable quantity in several counties discussed is described in some detail.

Campbell, J. L., Report upon the improvement of the Kankakee River and the drainage of the marsh lands in Indiana, 34 pp. with map of Kankakee region, Indianapolis, 1883.

Presents a line of levels along the axis of the Kankakee basin.

Campbell, J. T., Topographical phenomena in Indiana: Am. Naturalist, vol. 18, 1884, pp. 367–379.

Explains low inclination of south-facing drift slopes by a creeping of the deposits, favored by the deposition of drift by a southward-moving current of ice. Distrusts interpretation referring the low inclination to alternations of freezing and thawing on that slope.

——— Source of supply to lateral and medial moraines: Abstract in Proc. Am. Assoc. Adv. Sci., vol. 40, 1891, pp. 255–256.

Lower layers of ice are thought to bring up material to higher levels at abrupt bends as streams do.

——— Evidence of a local subsidence in the Interior: Jour. Geology, vol. 9, 1901, pp. 437–438.

Recent levelings of a locality in Indiana where bench marks were established in 1883 show a southward differential depression which it is thought may have been produced by the Charleston earthquake.

Carney, Frank, The metamorphism of glacial deposits: Jour. Geology, vol. 17, 1909, pp. 473–487.

Discusses induration or cementation, leaching, etc., in Illinoian drift compared with Wisconsin.

——— Raised beaches of the Berea, Cleveland, and Euclid sheets, Ohio: Bull. Sci. Lab. Denison Univ., vol. 14, 1909, pp. 262–287. Abandoned shore lines of the Oberlin quadrangle, Ohio: Bull. Sci. Lab. Denison Univ., vol. 15, 1910, pp. 101–117.

These two papers present results of detailed field study of beaches in several quadrangles on the south shore of Lake Erie.

——— Some proglacial lake shore lines of the Bellevue quadrangle, Ohio: Bull. Sci. Lab. Denison Univ., vol. 17, March, 1913, pp. 231–246, 4 figs.

Carr, M. E., and McLandon, W. E., Soil survey of the Saginaw area, Michigan: Field operations Bur. Soils in 1904, U. S. Dept. Agri., 1905, 40 pp. and map.

Discusses soils, agricultural methods, and conditions in an area of 984 square miles around Saginaw.

Chalmers, Robert, Artesian borings, surface deposits, and ancient beaches in Ontario: Summary Rept. Geol. Survey Canada for 1902, pp. 268–279.

Notes occurrence of two bowlder clays and presents discussion (with map) of several shore lines in southwestern Ontario. Differential uplift is recognized, but the amount of uplift is not determined.

CHAMBERLIN, T. C., On the extent and significance of the Wisconsin Kettle moraine: Trans. Wisconsin Acad. Sci., vol. 4, 1878, pp. 201-234.

Describes the morainic features and their relation to striæ in eastern Wisconsin, and the topographic relations and position of the moraine from Wisconsin eastward to the Atlantic coast. The development of ice lobes in each of the great basins is discussed and mapped.

——— Le Kettle moraine et les mouvements glaciaires que lui ont donné naissance: Compt. rend. Cong. géol. internat., sess. 1878, Paris, 1880, pp. 254-268.

Brings out the influence of basins in developing lobes of ice as determined by the distribution of the Kettle moraine and the striæ bearing toward it.

——— The bearing of some recent determinations on the correlation of the eastern and western terminal moraines: Am. Jour. Sci., 3d ser., vol. 24, 1882, pp. 93-97.

States that the moraines which stand at the drift border in the eastern part of the United States lie far inside (north of) the drift border in the interior.

——— Origin of the Great Lakes basins and the Great Lakes epoch: Geology of Wisconsin, vol. 1, 1883, pp. 288-295.

Discusses the ancient lake deposits, the changes of level, the reversal of drainage, and the work of the present lakes. In vol. 2, 1877, pp. 231-232, gives statement showing the rate of erosion of the lake shore in Racine County, Wis., which throws light on the length of time Lake Michigan has been at work.

——— Preliminary paper on the terminal moraine of the second glacial epoch: Third Ann. Rept. U. S. Geol. Survey, 1883, pp. 291-402.

Defines the several classes of drift and types of drift topography. Gives a comprehensive treatment of glacial lobation and describes a prominent morainic system whose course is outlined from the Atlantic seaboard to the Missouri Coteau.

——— The rock scorings of the great ice invasions: Seventh Ann. Rept. U. S. Geol. Survey, 1888, pp. 174-248.

Discusses and illustrates various phases of glacial scoring in the United States and British Columbia.

——— Bowlder belts distinguished from bowlder trains: Bull. Geol. Soc. America, vol. 1, 1890, pp. 27-31.

Says that bowlder belts conform to distribution of moraines, and bowlder trains to the bearing of striæ.

——— The attitude of the eastern and central portions of the United States during the glacial period: Am. Geologist, vol. 8, 1891, pp. 267-275.

In the earlier stages of glaciation the outwash from the ice was weaker and the attitude of the land probably flatter than in the later stages, though in the eastern portion the altitude was low at the close of glaciation.

——— Nature of the englacial drift of the Mississippi basin: Jour. Geology, vol. 1, 1893, pp. 47-60.

Treats of the amount and character of englacial drift, and outlines the course of bowlder belts in Indiana and Ohio which are thought to represent englacial transportation.

——— Glacial phenomena of North America: Geikie's Great ice age, 3d ed., 1895, pp. 724-775.

A comprehensive statement of North American glaciology. Names for the Kansan, Iowan, and Wisconsin drift sheets are introduced.

——— Classification of American glacial deposits: Jour. Geology, vol. 3, 1895, pp. 270-277; vol. 4. 1896, pp. 872-876.

Extends nomenclature given in Geikie's Great ice age so as to include the Illinoian drift sheet and the several interglacial soils or weathered zones.

——— An attempt to frame a working hypothesis of the cause of glacial periods on an atmospheric basis: Jour. Geology, vol. 7, 1899, pp. 545-584, 667-685, 751-787.

The function of carbon dioxide, the agencies of depletion and enrichment, and the varying rates of action are considered and applied to known glacial periods and to the oscillations from glacial to interglacial epochs; discusses also the agencies of localization of glaciation.

——— A contribution to the theory of glacial motion: Decen. Pub. Univ. Chicago, vol. 9, 1904, pp. 193-206.

Asserts that the differences between glacial ice and ice formed by freezing water are such that experiments on one throw little light on the other. The behavior of glacial ice under gravitative stress is discussed at some length.

——— and SALISBURY, R. D., The Pleistocene or glacial period: Geology, vol. 3, 1906, pp. 327-516, especially pp. 394-405.

CHAPMAN, E. J., Notes on the drift deposits of western Canada and on the ancient extension of the lake area of that region: Canadian Jour., new ser., vol. 6, 1861, pp. 221-229; vol. 8, 1863, pp. 457-462.

Notes occurrence of existing species of fresh-water mollusks in stratified drift and old lake ridges. Disputes Lyell's interpretation that high beaches around Lake Ontario were formed about an arm of the ocean and suggests that they were produced by a fresh-water lake.

CLAPP, F. G., and FULLER, M. L., The marl loess of the lower Wabash Valley: Bull. Geol. Soc. America, vol. 14, 1903, pp. 153-176.

Attempts to discriminate between water-laid and wind-deposited loess.

CLAYPOLE, E. W., On the preglacial geography of the region of the Great Lakes: Canadian Naturalist, vol. 8, 1878, pp. 187-206; vol. 9, 1881, pp. 213-227.

Bases discussion on data from borings.

——— Preglacial origin of the basins of Lakes Erie and Ontario: Proc. Am. Assoc. Adv. Sci., vol. 30, 1882, pp. 147-159.

Opposes hypothesis of glacial excavation of the lake basins on the ground that the amount of drift was inadequate to refill them. Cites observations in support of view that the basins are in the line of old river valleys.

CLAYPOLE, E. W., Buffalo and Chicago, or "What might have been": Am. Naturalist, vol. 20, 1886, pp. 856–862.
A slight change only is needed to divert the drainage of Lakes Superior, Michigan, Huron, and Erie from Niagara to the Chicago outlet.

CLINTON, DE WITT, On certain phenomena of the Great Lakes of North America: Trans. New York Lit. and Phil. Soc., vol. 2, 1817, pt. 1, pp. 1–33.
Discusses annual and short-period fluctuations of lake level.

COLE, L. J., The delta of the St. Clair River: Geol. Survey Michigan, vol. 9, 1903, pt. 1, pp. 1–28.
Discusses the character and extent of the delta and its present rate of growth. Evidence is found that the Lake St. Clair bed has been a land surface during part of the postglacial time, presumably while the Nipissing Great Lakes were discharging eastward past North Bay, Ontario.

COLLETT, JOHN, Reports of Indiana Geological Survey contain brief discussions of glacial deposits, as follows: Sullivan County, Second Ann. Rept. Geol. Survey Indiana, 1870, pp. 225–228; Dubois, Pike, Jasper, White, Carroll, Cass, Miami, Wabash, and Howard counties, Third and Fourth Repts., 1871 and 1872, pp. 193–195, 240–241, 291–293; Warren and Knox counties, Fifth Rept., 1873, pp. 191–195, 315–320; Brown County, Sixth Rept., 1874, pp. 77–84; Owen and Montgomery and part of Clay County, Seventh Rept., 1875, pp. 301–308, 361–371, 393, 401–409, 423–426; Shelby County, Eleventh Ann. Rept. Dept. Geology and Nat. Hist., 1881, pp. 56–69; Posey County, Thirteenth Rept., 1883, pp. 45–48.

COMSTOCK, F. M., Ancient lake beaches on the islands of Georgian Bay: Am. Geologist, vol. 33, 1904, pp. 310–318.
Describes beaches on three islands in the southeast arm of Georgian Bay.

COOPER, W. F., Water supply of the lower peninsula of Michigan: Rept. State Board Geol. Survey for 1903, pp. 47–95.
Briefly discusses artesian areas, springs, wells, topography, and water power in Lenawee, Hillsdale, Branch, St. Joseph, and Cass counties, and records of wells in other parts of the peninsula.

——— Geology of Bay County, Mich.: Rept. State Board Geol. Survey for 1905, pp. 137–426.
Presents records of coal borings in which glacial deposits are conspicuous.

——— Water supplies of Bay County, Mich.: Water-Supply Paper U. S. Geol. Survey No. 183, 1906, pp. 115–120.
Chiefly a discussion of underground waters and especially of flowing wells.

——— Geology and physical geography of Michigan: Ninth Rept. Mich. Acad. Sci., 1907, pp. 136–144.
Gives planimeter measurements of areas between each 100-foot contour based on Pl. II, Water-Supply Paper U. S. Geol. Survey No. 182, 1906.

COULTER, J. M., Some glacial action in Indiana: Science, vol. 2, 1883, p. 6; vol. 3, 1884, pp. 748–749.
Gives bearing of glacial striæ near Darlington.

COWLES, H. C., The physiographic ecology of northern Michigan: Science, vol. 12, 1900, pp. 708–709; Bot. Gazette, vol. 31, 1901, pp. 73–182.
The physiographic ecology of a large area at the head of Lake Michigan is discussed with fullness in the Botanical Gazette article.

COX, E. T., Jackson County, Ind.: Sixth Rept. Geol. Survey Indiana, 1874, pp. 41–42, 55–60.
Recognizes "Chestnut Ridge" to be morainic and gives well sections along it.

——— Glacial drift: Combined Eighth, Ninth, and Tenth Ann. Repts. Geol. Survey Indiana, 1876, 1877, and 1878, pp. 98–120.
Discusses glaciation generally and gives an outline of the extent of drift and the direction of the ice movement.

DAVIS, C. A., Bot. Gazette for June, 1898, pp. 453–455.
Discusses the geologic history of the tract at the head of Saginaw Bay and the several resulting types of soil.

——— A contribution to the natural history of marl: Jour. Geology, vol. 8, 1900, pp. 485–503; vol. 9, 1901, pp. 491-506. Also Geol. Survey Michigan, vol. 8, pt. 3, 1903, pp. 65–102.
Refers the accumulation of marl largely to the genus Chara.

——— Flowing wells of part of Oakland County, Mich.: Water-Supply Paper U. S. Geol. Survey No. 182, 1906, pp. 184–188. Flowing wells and municipal water supplies of the southern part of the Saginaw Bay drainage basin in Michigan: Water-Supply Paper U. S. Geol. Survey No. 183, 1907, pp. 121–245.
These water-supply reports discuss morainic and other glacial features, including the deposits of the glacial lakes, and give numerous well records showing the structure of the glacial deposits.

——— Peat deposits of the Ann Arbor quadrangle: Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1908.
Briefly discusses the occurrence and uses of peat.

——— Peat, essays on its origin, uses, and distribution in Michigan: Rept. State Board Geol. Survey Michigan for 1906, pp. 93–395.
Discusses the ecology of peat formation, the formation, character, and distribution of peat bogs in the northern peninsula, and the economics of peat in considerable detail.

——— Geology of the Walnut Lake region: Ann. Rept. State Board Geol. Survey Michigan for 1907, pp. 164–173.
Briefly discusses the glacial geology of part of Oakland County, Mich.

——— Glacial phenomena in the Marquette region: Ninth Rept. Michigan Acad. Sci., 1907, pp. 132-135.
Discusses the probable influence of the Huron Mountains on glacial movements.

——— Peat deposits as geological records: Tenth Rept. Michigan Acad. Sci., 1908, pp. 107–112.
Considers the varying rate of peat growth in the light of geologic conditions and directs attention to submerged peat beds on the Atlantic coast.

DAVIS, C. A., Geology of Tuscola County, Mich.: Rept. State Board Geol. Survey Michigan for 1908, pp. 121–346, 1909.
Discusses in considerable detail the physical geography, glacial features, soils, bedrock geology, native vegetation, and underground-water supplies. A topographic map based on railroad and drainage-ditch levels and aneroid observations brings out clearly the leading glacial and physiographic features.

DAVIS, W. M., The ancient outlet of Lake Michigan: Pop. Sci. Monthly, vol. 46, 1895, pp. 217–229.
Reviews previous descriptions and presents results of field study and topographic maps along the outlet.

DAWSON, J. W., Acadian geology, London, 3d ed., 1878, pp. xxvi, 697, suppl. 102 pp.
Refers the excavation of the Great Lakes to a time of continental submergence when polar currents flowing southward cut deeply into the strata. Considers the so-called lake ridges, moraines, and osars to be the record of old sea margins (pp. 70–71, suppl. pp. 18–24).

——— Canadian ice age, Montreal, 1893, 301 pp.
A compilation of numerous papers dealing almost entirely with Pleistocene deposits in Canada. The discussion of Pleistocene fossils is especially valuable.

DESOR, ÉDOUARD, Superficial deposits of the Lake Superior land district: Foster and Whitney Rept., Ex. Doc. No. 4, 31st Cong., 1st sess., 1851, pp. 232–270. Also Am. Jour. Sci., 2d ser., vol. 13, 1851, pp. 93–109.
Discusses the several classes of drift, the terraces, and the high beaches, and concludes that glaciation was followed by deep submergence. Also discusses modern shore phenomena and stream work.

——— Dunes on the shores of the upper American lakes: Proc. Boston Soc. Nat. Hist., vol. 3, 1853, p. 207; vol. 4, 1854, pp. 41–42.
Remarks that though no tidal action is present sand flats are exposed to wind action.

DOUGLAS, C. C., Report on Ingham and parts of Eaton and Jackson counties, Mich.: Second Ann. Rept. State Geologist, H. Doc. No. 13 (No. 4), 1839, pp. 66–77.
Briefly discusses drift and describes the two gravel ridges known as the Mason and the Williamstown-Dansville eskers.

——— General remarks on marl and other deposits and features of Jackson, Calhoun, Kalamazoo, Eaton, Ionia, and Kent counties: Third Ann. Rept. State Geologist, H. Doc. No. 8, 1840, pp. 54–62.

——— Remarks on the general character of the northern portion of the lower peninsula: Fourth Ann. Rept. State Geologist, H. Doc. No. 27, 1841, pp. 98–111.
Discusses topography and great thickness of drift. Notes a shore line (Algonquin beach) on Mackinac Island and bordering mainlands and estimates it to be 140 feet above the lake.

DRYER, C. R., Reports on counties in Indiana as follows: Dekalb and Allen counties: Sixteenth Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1889, pp. 98–130; Steuben and Whitley counties: Seventeenth Rept., 1892, pp. 114–134, 160–170; Noble and Lagrange counties: Eighteenth Rept., 1894, pp. 17–32, 72–82; Drift of the Wabash-Erie region: Eighteenth Rept., 1894, pp. 83–90.
In large part describe the glacial deposits. The Allen County report names Lake Maumee and describes its beach.

——— Studies in Indiana geography, Inland Pub. Co., Terre Haute, 1897, 110 pages.
Treats geographic features, glacial deposits (by Leverett), the Erie-Wabash region and morainic lakes of Indiana; discusses natural resources and changes produced by civilization; short history of the Great Lakes (by Taylor).

——— Eskers and esker lakes of northeastern Indiana: Jour. Geology, vol. 9, 1901, pp. 123–129.
Suggests "esker lake" as name for bodies of water occupying depressions closely connected with esker ridges.

EDMUNDS, E. S., Geology of Lagrange County, Ind.: Kansas City Review, vol. 2, 1879, pp. 500–508; vol. 3, 1880, pp. 28–33.
Very discursive; bears a little on Lagrange County.

ELLIS, R. W., Road materials of southeastern Indiana: Thirtieth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1905, pp. 766–871.
Pertains only in part to glacial deposits, and those chiefly the glacial gravels of the Ohio Valley and of the East White River valley.

ELROD, M. N., Reports on Quaternary features and deposits of counties in Indiana as follows: Bartholomew County: Eleventh Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1881, pp. 150–172; Decatur County: Twelfth Rept., 1882, pp. 139–145; Rush County: Thirteenth Rept., 1883, pp. 100–107; Fayette and Union counties: Fourteenth Rept., 1884, pp. 41–47, 55–58, 61–64, 70–71.
Notes a buried soil between drift sheets in much of the region covered. Approximately outlines the extent of the later or Wisconsin drift.

——— and BENEDICT, A. C., Geology of Wabash County, Ind.: Seventeenth Ann. Rept. Geology and Nat. Res. Indiana, 1891, pp. 238–255; Geology of Cass County: Nineteenth Rept., 1894, pp. 17–39.
Presents drift sections and well records and briefly discusses drift deposits.

FAIRCHILD, H. L., Glacial waters in the Lake Erie basin: Bull. New York State Mus. No. 106, 1907, 86 pp.
Discusses the glacial recession from the highlands south of Lake Erie to the basin of Lake Ontario, with special reference to the ice-border drainage. Gives very little information concerning the moraines but interprets the lake history somewhat elaborately.

FAIRCHILD, H. L., Drumlins of central western New York: Bull. New York State Mus. No. 111, 1907, 52 pp. and 47 pls.

Gives a full description and interpretation, accompanied by contour maps and numerous photographic illustrations, of one of the principal drumlin areas of North America. Evidence in support of the constructional development by slow accretion is clearly presented.

——— Pleistocene geology of New York State: Bull. Geol. Soc. America, vol. 24, No. 1, Mar. 25, 1913, pp. 133–162; Science, new ser., vol. 37, Feb. 14 and 21, 1913, pp. 237–249, 290–299.

FALL, DELOS, Marl and clay analyses: Geol. Survey Michigan, vol. 8, pt. 3, 1903, pp. 352–353.

Gives 37 analyses, chiefly by Fall.

FARNSWORTH, P. J., The Great Lake basins: Science, vol. 20, 1892, p. 74.

Presents the outgrown view that the lakes are pools left by the old "Azoic" sea.

FEATHERSTONAUGH, G. W., On the ancient drainage of North America and the origin of the cataract of Niagara: Am. Jour. Geology and Nat. Sci., vol. 1, 1831, pp. 13–21.

Not examined.

FIPPEN, E. O., and RICE, T. D., Soil survey of Allegan County, Mich., Bur. Soils U. S. Dept. Agr., 1901, pp. 93–124, with map.

Brings out imperfectly the relation of the soils to the ice sheet by a classification based upon mechanical analyses.

FINCH, JOHN, Age of basins of Lake Erie and St. Lawrence River: Am. Jour. Sci., vol. 27, 1835, p. 151.

FOSTER, J. W., Presidential address before American Association for the Advancement of Science: Proc. Am. Assoc. Adv. Sci., vol. 19, 1871, pp. 1–19.

Notes the occurrence of marine crustaceans in Lake Michigan and argues that they indicate a former connection between the Great Lakes and the ocean.

FOSTER, J. W., and WHITNEY, J. D., Ex. Doc. No. 4, 31st Cong., special sess. Sen., 1851, pp. 176–177, 183–189.

Briefly discusses the origin of the basins of Lakes Michigan and Huron and the evidences of denudation and subsidence.

FULLER, M. L., Pleistocene geology: Ditney folio (No. 84), Geol. Atlas U. S., U. S. Geol. Survey, 1902.

Recognizes and discusses glacial, water-laid, and wind deposits of southwestern Indiana.

——— Failure of wells along the lower Huron River, Mich., in 1904: Rept. State Geologist for 1904, pp. 1–29, Pl. I. Also Water-Supply Paper U. S. Geol. Survey No. 129, 1906, pp. 129–147.

Ascribes the failure in large part to deficiency of rainfall the previous year, supplemented, perhaps, by a general lowering of the water table by ditching. Negatives the popular view that the deficiency is due to the draft made by a large flowing well on Grosse Isle.

——— Flowing wells and municipal water supplies of Oceana, Newaygo, Mecosta, and Osceola counties, Mich.: Water Supply Paper U. S. Geol. Survey No. 183, 1906, pp. 46–81, 83–90.

Describes several artesian areas, general underground-water conditions, and the public supplies at villages.

——— and CLAPP, F. G. See Clapp and Fuller.

GEER, GERARD DE, Isobases of the postglacial elevation: Am. Geologist, vol. 9, 1892, pp. 247–249.

Briefly outlines results of studies chiefly in the lower St. Lawrence basin.

——— On Pleistocene changes of level in eastern North America: Proc. Boston Soc. Nat. Hist., vol. 25, 1892, pp. 454–477; Am. Geologist, vol. 11, 1893, pp. 22–44.

Presents measurements of marine limits and corresponding isobases. Refers the changes of level largely to the removal of the ice cap.

GEIB, W. J., and RICE, T. D., Soil survey of the Munising area, Mich.: Field Operations Bur. Soils for 1904, U. S. Dept. Agr., 1905, 25 pp. and map.

Discusses soils and agricultural conditions and adaptation for sugar beets in an area of 407 square miles on the Lake Superior shore near Munising.

——— and WILDER, H. J., Soil survey of the Pontiac area, Mich.: Field Operations Bur. Soils for 1903, U. S. Dept. Agr., 1904, 26 pp. and map.

Discusses soils and agricultural methods and conditions in an area of about 307 square miles around Pontiac.

GIBSON, JOHN, Geology of the lakes, etc.: Am. Jour. Sci., vol. 29, 1836, pp. 201–213.

Refers the lakes to the scouring action of a great deluge which came from the northwest and which also deposited the drift.

GILBERT, G. K., Surface geology of the Maumee Valley: Geology Ohio, vol. 1, 1873, pp. 535–590; brief discussion in Am. Jour. Sci., 3d ser., vol. 1, 1871, pp. 339–345.

Describes relation of drainage to moraines and discusses the extent of a lake in the Maumee basin and its outlet to the Wabash past Fort Wayne. Suggests that a land barrier that has now disappeared held up this lake. In a footnote (p. 552) Newberry suggests that the barrier was an ice dam.

——— Topographic features of lake shores: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 69–123.

Discusses the work of waves and the several classes of shore features; gives a number of illustrations drawn from Michigan.

——— Changes of level of the Great Lakes: The Forum, vol. 5, 1888, pp. 417–428.

Discusses chiefly the fluctuations due to climatic changes.

Gilbert, G. K., Recent earth movements in the Great Lakes region: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898, pp. 601–647 (briefly discussed in Nat. Geog. Mag., vol. 8, 1897, pp. 233–247).

Discusses the evolution of the Great Lakes from the disappearance of the ice sheet to the present, and considers the earth movements which have tilted the beaches and drowned the valleys on part of the coast. Outlines a plan to test the present rate of uplift by measurements of lake levels at a series of stations.

Goldthwait, J. W., Correlation of the raised beaches on the west side of Lake Michigan: Jour. Geology, vol. 14, 1906, pp. 411–424.

Chiefly discusses the Algonquin and Nipissing beaches but includes notes on the beaches of Lake Chicago.

——— Abandoned shore lines of eastern Wisconsin: Bull. Wisconsin Geol. Survey, No. 17, 1907, 134 pp.

Reports in detail the results of wye-level measurements of Algonquin and Nipissing beaches on the borders of Lake Michigan and Green Bay in Wisconsin and points out that they throw light on the differential uplift.

——— Reconstruction of water planes of the extinct glacial lakes in the Lake Michigan basin: Jour. Geology, vol. 16, 1908, pp. 459–476. Abstract in Science, vol. 27, 1908, pp. 724–725. Discusses the differential uplift on opposite sides of Lake Michigan.

——— Isobases of the Algonquin and Iroquois beaches and their significance: Bull. Geol. Soc. America, vol. 21, 1910, pp. 227–248.

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——— and Atwood, W. W., Physical geography of the Evanston-Waukegan region: Bull. Illinois Geol. Survey No. 77, 1908, 102 pp.

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Gorby, S. S., Reports on Pleistocene features of counties in Indiana, as follows: Tippecanoe County: Fifteenth Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1886, pp. 61–71, 87–96; Benton County: Idem, pp. 212–220; Miami County: Sixteenth Rept., 1888, pp. 170–178.

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——— and Lee, S. E. See Lee and Gorby.

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Presents an incorrect correlation of outlets from observations taken on a bicycle trip made across the State.

——— Geological report on Sanilac County, Mich.: Mich. Geol. Survey, vol. 7, pt. 3, 1900, pp. 3–6, 13–20, 25–26.

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——— Wave cutting on west shore of Lake Huron, Sanilac County, Mich.: Rept. State Board Geol. Survey Michigan for 1901, pp. 283–290.

Compares a resurvey of part of the shore in 1901 with the shore line shown by the land survey in 1823 and with the lake chart of 1858, and gives historical data showing variations in rate of cutting. Includes several instructive views.

Gregory, W. M., Report on Arenac County, Mich.: Rept. State Board Geol. Survey Michigan for 1901, pp. 9–29.

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——— Recent shore forms: Rept. State Board Geol. Survey Michigan for 1903, pp. 301–305.

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——— The Alabaster area: Geol. Survey Michigan, vol. 9, pt. 2, 1904, pp. 60–66.

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Discusses distribution of diamonds in the glacial deposits from Minnesota to Ohio.

——— Late glacial and postglacial uplift of the Michigan basin: Pub. Michigan Geol. Survey No. 5, Geol. ser. 3, 1911, 68 pp.

Discusses uplift west of north part of Lake Michigan in Michigan.

HORTON, R. E., Drainage districts and available water power of Michigan: Michigan Eng., 1901, 22 pp.

HOUGHTON, DOUGLASS, Brief discussion of hydraulic power of streams and leading topographic features of southern Michigan: First Ann. Rept. State Board Geol. Survey Michigan, 1838, pp. 276–316.

——— Further discussion of drainage, topography, and drift of the southern peninsula: Second Ann. Rept. State Board Geol. Survey Michigan, 1839, pp. 380–410.

Later reports by Douglass Houghton contain only incidental references to the glacial deposits.

——— Land survey plats in the northern peninsula.

The land survey plats of townships surveyed by Douglass Houghton contain numerous notes on the geology of the region covered by them.

HOY, P. R., Deep-water fauna of Lake Michigan: Trans. Wisconsin Acad. Sci., vol. 1, 1870, pp. 98–101.

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——— Report on Lenawee, Hillsdale, Branch, St. Joseph, Cass, Berrien, Washtenaw, Oakland, and Livingston counties, with notes on the lake ridges and Great Lakes: Third Ann. Rept. State Board Geol. Survey Michigan, 1840, H. Doc., vol. 2, pp. 259–284.

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——— Erratics, diluvial and alluvial deposits, lake ridges, etc.: Fourth Ann. Rept. State Board Geol. Survey Michigan, 1841, Joint Doc., pp. 552–578.

——— Geology and topography of district south of Lake Superior: In Rept. by Houghton and Bristol on Geography, topography, and geology of the survey of mineral region of the south shore of Lake Superior, 1846, pp. 21–38. Also House Ex. Doc. No. 5, pt. 3, 1849, pp. 833–842, 882–898, 899–932.

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——— A Finger Lake bed in Ashland and Wayne counties, Ohio, with tilted shore lines: Am. Jour. Sci., 4th ser., vol. 37, 1914, pp. 444–450.

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The Algonquin shore line is reported to have a length of 450 miles in Simcoe County and to be clearly separable both from lower and higher shore lines, all of which are considered marine.

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KEDZIE, R. C., The following papers included in the annual reports of the Michigan Board of Agriculture contain numerous analyses and discussions of the properties of the soils: Rept. for 1878, pp. 386–403, analyses of soils of the northern counties; Rept. for 1887, pp. 317–325, problem of the pine plains and analyses of soils; Rept. for 1888, pp. 207–211, soils of the experimental farm near Grayling, and average compositions of six soils; Rept. for 1893, pp. 403–415, analyses of soils grouped according to their value for certain products.

KLIPPART, J. H., The Maumee Valley: Progress Rept., Geol. Survey Ohio, 1870, pp. 320–400.

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LANE, A. C., Geology of lower Michigan with reference to deep borings: Mich. Geol. Survey, vol. 5, 1895, pt. 2, pp. 1–100, Pls. I–LXXIII.

Presents records of glacial deposits penetrated, as well as underlying formations.

——— Water resources of the lower peninsula of Michigan: Water-Supply Paper U. S. Geol. Survey No. 30, 1899, 97 pp.

Describes general physiographic and geologic features as well as water supply.

——— Geological report on Huron County, Mich.: Michigan Geol. Survey, vol. 7, 1900, pt. 2, pp. 1–329.

Describes Pleistocene features and deposits as well as hard-rock geology. Makes an estimate of time since the ice sheet disappeared.

——— Ann. Rept. State Board Geol. Survey Michigan for 1901, 304 pp.

Includes notes on Pleistocene topics and county reports (on Alcona County by Leverett, Arenac County by Gregory, and Lapeer County by Taylor).

LANE, A. C., Coal of Michigan: Michigan Geol. Survey, vol. 8, 1902, pp. 1–233. Includes numerous notes on thickness and character of glacial deposits.

—— Analyses of lower peninsula waters: Rept. State Board Geol. Survey Michigan for 1903, pp. 96–109.
Analyses of river, drift water, and rock water.

—— Waters of the upper peninsula of Michigan: Rept. State Board Geol. Survey Michigan for 1903, pp. 113–167.

—— Deep borings for oil and gas: Rept. State Board Geol. Survey Michigan for 1903, pp. 271–294.
Notes on glacial deposits appear in connection with the records of deeper strata.

—— Notes on the origin of Michigan bog limes: Michigan Geol. Survey, vol. 8, 1903, pp. 199–342.
Includes notes on localities and mills.

—— Water supplies of Lansing and vicinity: Water-Supply Paper U. S. Geol. Survey No. 182, 1906, pp. 170–176.

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LANMAN, J. H., History of Michigan, civil and topographical, with a view of the surrounding lakes, accompanied by a map, New York, E. French, printer. 1839, pp. 249–281.
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LAPHAM, I. A., Reference to a former high stage of Lake Michigan: Proc. Boston Soc. Nat. History, vol 3, 1850, pp. 291–292.
Notes evidence of a lake beach 24 feet above present beach.

LAWSON, A. C., Coastal topography of the north side of Lake Superior with special reference to the abandoned strands of Lake Warren: Twentieth Ann. Rept. Geol. and Nat. Hist. Survey Minnesota, 1893, pp. 181–289. Abstract in Am. Geologist, vol. 11, 1893, pp. 356–357.
Presents numerous data concerning beaches at different altitudes and of different ages. Finds 33 stages of Lake Superior and makes surface at each stage substantially level as compared with present lake surface. For different interpretations and opposing evidence, see Taylor, F. B., Am. Geologist, vol. 15, 1895, pp. 304–314.

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The revision brings in the latest results of Pleistocene investigations.

LEE, S. E., and GORBY, S. S., Geology of Boone County, Ind.: Fifteenth Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1886, pp. 160–176.
Gives many well sections, some of which show buried soil between drift sheets.

—— and THOMPSON, W. H., Maxinkuckee: Fifteenth Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1886, pp. 182–186.
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LESLEY, J. P., Origin and drainage of the Great Lakes: Proc. Am. Phil. Soc., vol. 20, 1883, pp. 95–101.
Presents evidence that erosion by ice was a minor factor in determining the size and form of the basins

LEVERETT, FRANK, Raised beaches of Lake Michigan: Trans. Wis. Acad. Sci., vol. 7, 1888, pp. 177–192.
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—— Correlation of moraines with raised beaches of Lake Erie: Am. Jour. Sci., 3d ser., vol. 43, 1892, pp. 281–301. Abstract in Trans. Wisconsin Acad. Sci., vol. 8, 1892, pp. 233–240.
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—— White clays of the Ohio region: Am. Geologist, vol. 10, 1892, pp. 18–24.
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—— Water resources of Indiana and Ohio: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1897, pp. 419–559.
Discusses glacial features and drainage, underground waters, and city supplies.

—— The glacial deposits of Indiana: Dryer's Studies in Indiana geography, pp. 28–41, Inland Pub. Co., 1897, Terre Haute, Ind.
Discusses the glacial gathering grounds and the glacial succession in Indiana, as well as the deposits made by the ice sheet.

—— Pleistocene features and deposits of the Chicago area: Bull. Geol. and Nat. History Survey Chicago Acad. Sci. No. 2, Chicago, 1897, 86 pp.
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—— Weathered zones and soils (Yarmouth and Sangamon) between drift sheets: Proc. Iowa Acad. Sci., vol. 5, 1897, pp. 71–86; also Jour. Geology, vol. 6, 1898, pp. 171–181, 238–243.
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—— The Peorian soil and weathered zone (the Toronto formation?): Jour. Geology, vol. 6, 1898, pp. 244–249.
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——— Wells of Indiana: Water-Supply Papers U. S. Geol. Survey Nos. 21 and 26, 1899, 82 and 64 pp.
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——— Surface geology of Alcona County, Mich.: Rept. State Geologist for 1901, pp. 35–64.
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Discusses and illustrates features of the drift and glacial lakes of southeastern Michigan.

——— Glacial geology of the Grand Rapids area, Michigan: Geol. Survey Michigan, vol. 9, pt. 2, 1904, pp. 56–59.
A brief outline of the main glacial features around Grand Rapids.

——— Review of the glacial geology of the southern peninsula of Michigan: Sixth Rept. Mich. Acad. Sci., 1905, pp. 100–110.
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——— Drumlins in the Grand Traverse (Mich.) region (abstract): Bull. Geol. Soc. America, vol. 16, 1906, p. 577.
Some drumlins appear to be sculptured from earlier deposits and some built up by slow accretion.

——— Flowing-well districts of the eastern part of the northern peninsula of Michigan: Water-Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 29–53.
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——— and others. Flowing wells and municipal water supplies of the southern part of the southern peninsula of Michigan: Water-Supply Paper U. S. Geol. Survey No. 182, 1906, xii, 292 pp. Flowing wells and municipal water supplies of the middle and northern parts of the southern peninsula of Michigan: Water-Supply Paper U. S. Geol. Survey No. 183, 1906, xii, 393 pp.
These two papers present reports by Bowman, Cooper, Davis (C. A.), Fuller (M. L.), Gregory (W. M.), Lane, McLouth, Nellist, Sherzer, and Udden (Jon A.), as well as by Leverett. Describes about 300 flowing-well areas, all public supplies in cities and villages having waterworks, and the general underground-water conditions of the peninsula.

——— Glacial formations and drainage history of the Ann Arbor quadrangle: Ann Arbor folio (No. 155), Geologic Atlas U. S., U. S. Geol. Survey, 1908.
Gives a brief description of the glacial and lake features, the drainage history, and the underground waters.

——— Weathering and erosion as time measures: Am. Jour. Sci., 4th ser., vol. 27, 1909, pp. 249–268.
Discusses the various drift sheets in America as affected by weathering and erosion and compares them with European drifts.

——— An outline of the history of the Great Lakes: Twelfth Rept. Michigan Acad. Sci., 1910, pp. 19–42.
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——— Surface geology and agricultural conditions of the southern peninsula of Michigan: Pub. Michigan Geol. and Biol. Survey No. 9, Geol. ser. 7, 1912, 144 pp.

——— Time relations of glacial lakes in the Great Lakes region [abstract]: Jour. Washington Acad. Sci., vol. 3, No. 8, 1913, pp. 237–238.

LEVETTE, G. M., Observations on surface geology and lakes of Dekalb, Steuben, Lagrange, Elkhart, Noble, St. Joseph, and Laporte counties, Ind.: Fifth Ann. Rept. Geol. Survey Indiana, 1873, pp. 430–474; Seventh Rept., 1875, pp. 469–503.
Presents notes on the topography, old shore lines, drainage, water power, flowing wells, peat, bog iron, and marl deposits, and gives determinations of depth, temperature, and molluscan fauna of the principal morainal lakes.

LIVINGSTON, B. E., Distribution of the plant societies of Kent County, Mich.: Rept. State Board Geol. Survey Michigan for 1901, pp. 81–103.
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——— The relation of soils to natural vegetation in Roscommon and Crawford counties, Mich.: Rept. State Board Geol. Survey Michigan for 1903, pp. 9–30.
A similar study to that in Kent County (notes above).

LOGAN, W. E., Superficial geology of the St. Lawrence Basin: Geology of Canada, 1863, pp. 886–930. (Summary by Dr. Robert Bell.)
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LYELL, CHARLES, On the ridges, elevated beaches, inland cliffs, and bowlder formations of the Canadian lakes and valley of the St. Lawrence: Am. Jour. Sci., vol. 46, 1844, pp. 314–317.
Presents general notes on each topic.

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Discusses soils and agricultural methods and conditions in the northern half of Shiawassee County, an area of 270 square miles.

MARSTERS, V. F., Topography and geography of Beanblossom Valley, Monroe County, Ind.: Proc. Indiana Acad. Sci., 1901, pp. 222–237.
Considers the preglacial, glacial, and postglacial history of the valley and its environs.

McBeth, W. A., Physical geography of the region of the great bend of the Wabash: Proc. Indiana Acad. Sci., 1899, pp. 157-161.

Contains discussions of drift topography and drainage peculiarities illustrated by a contour map in which the contours are greatly out of harmony with the slopes of the region.

——— The development of the Wabash drainage system and the recession of the ice sheet in Indiana: Proc. Indiana Acad. Sci., 1900, pp. 184-192.

Gives an interpretation of the recession of the ice sheet which is not in harmony with the moraines and attendant drainage.

——— Western Indiana bowlder belts: Proc. Indiana Acad. Sci., 1900, pp. 192-194.

Presents the old but discarded view that the bowlder belts are the product of floating ice in a lake.

——— Wabash River terraces in Tippecanoe County, Ind.: Proc. Indiana Acad. Sci., 1901, pp. 237-243.

Notes are presented on the altitude and structure of terraces of the Wabash and the occurrence of a deep preglacial valley along the part of the river in Tippecanoe County.

——— History of Wea Creek in Tippecanoe County, Ind.: Proc. Indiana Acad. Sci., 1901, pp. 244-247.

The history is interpreted on the hypothesis of the existence of transient lakes between moraines due to an assumed blocking of the Wabash Valley to the west by the ice sheet.

McCaslin, D. S., Reports on counties in Indiana as follows: Jay County: Twelfth Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1882, pp. 153-165; Johnson County: Thirteenth Rept., 1883, pp. 116-127.

Outlines the course of morainic ridges and other glacial features in Jay County, and discusses the structure and constitution of the drift. Notes the great number of bowlders in parts of Johnson County, but considers them the residue from the erosion of a thick till sheet instead of a deposit at the ice margin.

McLandon, W. E., and Carr, M. E. See Carr and McLandon.

McLouth, C. D., Topography, soils, water resources, etc., of Muskegon County, Mich.: Rept. State Board Geol. Survey Michigan for 1901, pp. 104-107.

——— Water supplies of Muskegon County: Water-Supply Paper U. S. Geol. Survey No. 183, pp. 25-45.

Discusses flowing-well areas and municipal supplies.

Montgomery, H. T., The Kankakee Valley: Proc. Indiana Acad. Sci., 1898, pp. 277-282.

Discusses the glacial drainage through the valley from the Lake Michigan, Saganaw, and Maumee lobes. Carries too much of the drainage from the Lake Michigan glacier past South Bend, and interprets part of the morainic systems of the Lake Michigan lobe to be a moraine of the Saginaw lobe.

Moore, Joseph, Glacial and preglacial erosion in the vicinity of Richmond, Ind.: Proc. Indiana Acad. Sci., 1892, pp. 27-29.

——— Morainal stone quarry of Upper Silurian limestone near Richmond, Ind.: Proc. Indiana Acad. Sci., 1896, pp. 75-76.

Moseley, E. L., Lake Erie enlarging: The Lakeside Magazine, Lakeside, Ohio, Apr., 1898, vol. 1, pp. 14-17.

Notes submerged stalactites, submerged stumps, and the character of insular flora and deduces from them an expansion of Lake Erie at its western end, which is referred to a recent tilting of the lake basins.

——— Submerged valleys in Sandusky Bay: Nat. Geog. Mag., vol. 13, 1902, pp. 398-403.

Reports that a submerged valley of Sandusky River and valleys of smaller streams continue across Sandusky Bay into Lake Erie, thus presenting another evidence of the recent tilting referred to in last-cited paper.

——— Formations of Sandusky Bay and Cedar Point [Ohio]: President's address in Proc. Ohio Acad. Sci., vol. 14, pt. 5, 1905, pp. 179-238.

Carefully discriminates between the tilting of the land and the variations of rainfall in producing differences in lake level. Estimates the encroachment of the lake in a century, as well as the total encroachment. Notes that Cedar Point is especially valuable in its storm beaches, whose dates are a matter of record, in showing the changes now in progress, and that Sandusky Bay is a good example of a drowned valley.

Mudge, E. H., Observations along the valley of Grand River, Michigan: Am. Geologist, vol. 12, 1893, pp. 284-288.

Describes glacial features of the region.

——— Drainage systems of the Carboniferous area of Michigan: Am. Geologist, vol. 14, 1894, pp. 301-308.

Describes the topography and discusses the origin of the river systems.

——— Central Michigan and the postglacial submergence: Am. Jour. Sci., 3d ser., vol. 50, 1895, pp. 442-445.

Brings evidence from a bar in the Grand River valley that a west-flowing stream of considerable strength and volume discharged from the Saginaw basin through this valley—evidence which opposes the view that the valley was occupied by a strait at sea level.

——— Some features of preglacial drainage in Michigan: Am. Jour. Sci., 4th ser., vol. 4, 1897, pp. 383-386.

Estimates southern peninsula of Michigan to have greatest average thickness of drift found in area of its size in North America, yet the old topography is not completely buried. Conjectures, by means of borings in the great depressions of the State, the general course of a few preglacial valleys. Accepts Spencer's interpretation that the main stream flowed from the Lake Michigan toward the Saginaw Bay basin; but gives a map showing that the valleys converge toward Lake Michigan.

——— Mouth of Grand River, Michigan: Am. Jour. Sci., 4th ser., vol. 8, 1899, pp. 31-34.

Describes deposits where Grand River enters the glacial lake outlet in eastern Ionia County that throw light upon the height of water in the outlet.

MUDGE, E. H., Further notes upon preglacial drainage in Michigan: Am. Jour. Sci., 4th ser., vol. 10, 1900, pp. 158–160.
Discusses the bearing of certain well records on old drainage.

NELLIST, J. F., Water supplies of Kent County, Mich.: Water-Supply Paper U. S. Geol. Survey No. 182, 1906, pp. 267–278.
Discusses flowing-well areas and municipal supplies.

NEWBERRY, J. S., The surface geology of the basins of the Great Lakes, etc.: Am. Naturalist, vol. 4, 1871, pp. 193–218. Also Annals New York Lyceum Nat. Hist., vol. 9, 1871, pp. 213–234. A briefer paper appears in Proc. Boston Soc. Nat. Hist., vol. 9, 1865, pp. 42–46.
Asserts that the lake basins have a connected drainage system lower than the present and suggests that this was followed by the ice sheet even to a movement from Lake Erie into Lake Ontario. Thinks that the ice produced the broad and deep boat-shaped basins, and that a large inland sea followed the glacial epoch and distributed bowlders and gravel and produced lake ridges.

——— On the structure and origin of the Great Lakes: Proc. New York Lyceum Nat. Hist., 2d ser., 1874, pp. 136–138.
Gives ice erosion as well as preglacial drainage a prominent rôle. A similar discussion appears in Proc. Am. Philos. Soc., vol. 20, 1883, pp. 91–95.

——— Surface geology: Geology of Ohio, vol. 2, 1874, pp. 1–80, 183–186, 197–204, 206–210.
Gives much attention to the origin and history of the Great Lakes. Earlier reports in Rept. Progress Ohio Geol. Survey for 1869, and in vol. 1, 1873, discuss the history of the Great Lakes to some extent.

——— Drift deposits of Indiana: Fourteenth Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1884, pp. 85–97.
Gives general résumé of the origin and structure of the drift deposits without special application to Indiana.

NEWSOM, J. F., Drainage of southern Indiana: Jour. Geol., vol. 10, 1902, pp. 166–181.
Compares postglacial and preglacial drainage and discusses effect of glaciation on drainage and on topography.

OWEN, RICHARD, Geological reconnaissance of Indiana, 1859–60, 368 pp., Indianapolis, 1862.
Briefly discusses glacial deposits in connection with notes pertaining to each of many counties in central and northern Indiana. Calls attention to Gilboa Ridge in Benton County, to bowlder belts in Benton and Warren counties, to gold in the drift of Carroll, Clinton, Henry, and Brown counties, and to numerous other Pleistocene features.

PETER, ROBERT, A report of the chemical analyses of 33 soils of Indiana: Owen's Geological reconnaissance of Indiana, 1859–60, pp. 241–268.

PHINNEY, A. J., Reports upon drift and surface geology of the following counties of Indiana: Delaware County: Eleventh Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1881, pp. 126–136; Randolph County: Twelfth Rept., 1882, pp. 177–184; Grant County: Thirteenth Rept., 1883, pp. 138–143; Henry County and parts of Randolph, Delaware, and Wayne counties: Fifteenth Rept., 1886, pp. 97–116.

——— The natural-gas field of Indiana: Eleventh Ann. Rept. U. S. Geol. Survey, 1891, pt. 1, pp. 589–742.
Presents many well records showing thickness of drift.

PIERCE, JAMES, Notice of the peninsula of Michigan in relation to its topography, scenery, agriculture, population, resources, etc.: Am. Jour. Sci., vol. 10, 1826, pp. 304–319.
Gives a good description for that early date.

PLUMMER, J. T., Geology about Richmond, Ind.: Am. Jour. Sci., vol. 44, 1843, pp. 281–313.
Notes the striæ, buried wood, bowlders, soils, springs, etc., in vicinity of Richmond, Ind.

PRICE, J. A., Road materials in Allen County, Ind.: Thirtieth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1905, pp. 275–314.
Discusses briefly the topography, drainage, both glacial and postglacial, and general glacial history of Allen County and the sand and gravel deposits in their generic relations. Describes in detail the workable deposits of gravel.

RAMSEY, A. C., On the glacial origin of certain lakes, etc.: Quart. Jour. Geol. Soc. London, vol. 18, 1862, pp. 185–204. Also Am. Jour. Sci., 2d ser., vol. 35, 1863, pp. 324–345.
Notes the abundance of lakes in glaciated regions, and shows that some of them are in rock basins apparently excavated by ice.

RICE, T. D., and FIPPEN, E. O. See Fippen and Rice.

——— and GEIB, W. J. See Geib and Rice.

RIES, HEINRICH, Clays and shales of Michigan: Michigan Geol. Survey, vol. 8, pt. 1, 1900, pp. 1–67.
Includes tests and uses of surface clays and glacial clays as well as of shales.

ROMINGER, CARL, Geology of the Lower Peninsula of Michigan: Michigan Geol. Survey, vol. 3, 1873–1876, pp. 1–22.
Thinks that glacial deposits were acted on by floods and floating ice late in the glacial epoch.

ROY, THOMAS, On the ancient state of the North American continent: Proc. Geol. Soc. London, vol. 2, 1837, pp. 537–538.
Refers all the terraces and gravelly ridges from the level of Lake Ontario up to 1,000 feet above sea to the action of a great lake.

RUSSELL, I. C., Sand bars in Lake Michigan and arms of the Great Lakes and of their hydrographic basins: Geologic history of Lake Lahontan: Mon. U. S. Geol. Survey, vol. 11, 1885, pp. 92–93.

——— Geologic history of the Laurentian basin: Jour. Geology, vol. 1, 1893, pp. 394–408.
A discussion of the problems connected with the Great Lakes.

——— Geography of the Laurentian basin: Bull. Am. Geog. Soc., vol. 30, 1898, pp. 226–254.
Presents a review of the glacial history of the Great Lakes region.

RUSSELL, I. C., Lakes of North America, Ginn & Co., Boston, 1897, pp. 96–104.

Contains a discriminating review of part of the literature of the Pleistocene Great Lakes.

——— The Portland cement industry in Michigan: Twenty-second Ann. Rept. U. S. Geol. Survey, 1900–1901, pt. 3, pp. 646–664.

Discusses the mode of occurrence, physical properties, chemical composition, and origin of marl deposits.

——— A geological reconnaissance along the north shores of Lakes Huron and Michigan: Rept. State Board Geol. Survey Michigan, 1904, pp. 33–113. A geologic reconnaissance in Menominee, Dickinson, and Iron counties, Mich.: Rept. State Board Geol. Survey Michigan for 1906, pp. 1–91.

These reports describe the glacial deposits, lake beaches, soils, and pre-Pleistocene geology, and give considerable attention to drumlins, which are said to have been chiefly formed by the sculpturing of a drift sheet that was overridden by the ice. Illustrated by several good photographs.

——— Drumlin areas in northern Michigan (abstract): Seventh Rept. Michigan Acad. Sci., 1905, pp. 36–37. Also Bull. Geol. Soc. America, vol. 16, 1906, pp. 577–578.

Discusses two drumlin areas, Le Cheneaux and Menominee, and infers that they are largely forms sculptured by a fresh ice advance over an earlier drift sheet.

——— Report on the water supply of the Ann Arbor Water Co.: Proc. Ann Arbor Council, Nov. 13, 1905, 22 pp.

Discusses the geological conditions at the wells of two pumping stations of the water company.

——— Marl deposits, bowlders, and bedrock geology of the Ann Arbor quadrangle: Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1906.

Discusses origin and extent of marl.

SALISBURY, R. D., and CHAMBERLIN, T. C. See Chamberlin and Salisbury.

SCHERMERHORN, L. Y., Physical characteristics of the northern and northwestern lakes: Am. Jour. Sci., 3d ser., vol. 33, 1887, pp. 278–284.

Gives area, watershed, length of shore lines, depth and character of bottom, rainfall, run-off, and fluctuations in level of each of the Great Lakes.

SCHOOLCRAFT, H. R., Narrative journal of travels in 1820 through the northwestern regions of the United States from Detroit to the Mississippi, Albany, 1821, 419 pp.

Reviews explorations by Marquette, Joliet, La Salle, Hennepin, La Hontan, Charlevoix, Alexander Henry, Carver, Hearne, and McKenzie in the Great Lakes region and the country to the north. Describes with much accuracy the shore features of Lake St. Clair, St. Clair River, west side of Lake Huron, both sides of Lake Michigan, and part of the south shore of Lake Superior, calling attention to the small extent of the rock outcrops and the universal presence of granitic and hornblendic rocks even on high points like Mackinac Island. Notes buried timber between sand deposits and blue clay near the head of St. Clair River, and remarks that the drift deposits or alluvium may be composed of several distinct formations.

——— Production of sand storms and lacustrine beds by causes associated with the North American Lakes: Proc. British Assoc., vol. 12, 1842, pp. 42–44. Also Am. Jour. Sci., vol. 44, 1843, pp. 368–370.

Describes encroachment of dunes on fertile land.

SCOVELL, J. T., Geology of Vigo County, Ind.: Twenty-first Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1897, pp. 546–565.

Discusses topography, ancient channels, recent valleys, glacial deposits, and soils.

——— Terraces of the lower Wabash: Proc. Indiana Acad. Sci., 1898, pp. 274–277.

——— Lake Maxinkuckee: Twenty-fifth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1900, pp. 233–247, 261–265.

Discusses the drainage basin, springs, flowing wells, topography, flora, marl, and mud deposits. Estimates age of lake to be between 8,000 and 12,000 years, from rate of deposition of marl.

——— Road material of a portion of western Indiana: Thirtieth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1905, pp. 571–653.

Discusses a preglacial channel followed in part by Wabash River, the terraces along the river, and the distribution of workable gravels on uplands.

SHERZER, W. H., Geological report on Monroe County, Mich.: Geol. Survey Michigan, vol. 7, pt. 1, 1900, 240 pp.

Discusses the glacial geology and lake history and the pre-Pleistocene formations; also treats climate, soils, water supplies, road materials, etc.

——— Ice work in southeastern Michigan: Jour. Geology, vol. 10, 1902, pp. 194–216.

Argues that the rock scorings show records of each of the great ice invasions.

——— Water supplies of Wayne County, Mich.: Water-Supply Paper U. S. Geol. Survey No. 182, 1906, pp. 48–78.

Devotes much space to the underground supplies; also discusses water power and public water supplies for Detroit and other cities.

——— Geological report on Wayne County, Mich.: Pub. Michigan Geol. and Biol. Survey No. 12, Geol. ser. 9, 1913, 388 pp., 32 pls., 22 figs.

SHEPHERD, FOREST, Remarks on a bowlder mass of native copper from the southern shore of Lake Superior: Am. Jour. Sci., 2d ser., vol. 4, 1847, pp. 115–116.

——— Observations on the drift furrows, grooves, scratches, and polished surfaces of the rocks of Lake Superior: Am. Jour. Sci., 2d ser., vol. 4, 1847, pp. 282–283.

SHUFELDT, G. A., On the subterranean sources of the waters of the Great Lakes: Am. Jour. Sci., 2d ser., vol. 43, 1867, pp. 193–197.

Suggests that much water may reach the lakes by underground courses.

SIEBENTHAL, C. E., Quaternary deposits of the Bedford limestone region: Twenty-first Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1896, pp. 300–303.

Outlines the glacial boundary and extent of small glacial lakes, and reports bearing of striæ near the glacial boundary.

——— Topography, Pleistocene deposits, and drainage of the hydraulic limestone area in southern Indiana: Twenty-fifth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1900, pp. 359–364.

SPENCER, J. W., Preglacial outlet of the basin of Lake Erie into that of Lake Ontario with notes on the origin of our lower Great Lakes: Proc. Am. Phil. Soc., vol. 19, 1882, pp. 300–337; Second Geol. Survey Pennsylvania, Rept. Q4, 1881, pp. 357–404.

Brings evidence of a deep channel leading from Lake Erie past Cayuga and Seneca, Ontario, into Dundas Valley and Lake Ontario.

——— Notes on the origin of the Great Lakes of North America: Proc. Am. Assoc. Adv. Sci., vol. 30, 1882, pp. 131–146.

Discusses relative value of theories concerning geological valleys, glacial erosion basins, atmospheric and fluvial erosion (obstructed by drift), and the need for some oscillation of level.

——— Warping of the earth's crust in relation to the origin of the basins of the Great Lakes: Am. Naturalist, vol. 21, 1887, pp. 168–171.

Infers a warping at the upper rapids of the Mississippi (probably incorrectly) and argues that warping extends into the Great Lakes region.

——— Lake beaches at Ann Arbor, Mich.: Am. Geologist, vol. 2, 1888, p. 62.

A brief note stating that his observations confirm those by Dr. Wooldridge. See also Wooldridge, C. W.

——— The St. Lawrence basin and the Great Lakes: Canadian Rec. Sci., vol. 3, 1888, pp. 232–235; Am. Geologist, vol. 2, 1888, pp. 346–348; Am. Naturalist, vol. 23, 1889, pp. 491–494.

Reports the discovery of the ancient course of St. Lawrence River, the origin of the basins of the Great Lakes, the establishment and dismemberment of Lake Warren, the outlet of the Huron-Michigan-Superior Lake into Lake Ontario by the Trent Valley, and states that Lake Erie is the youngest of all the Great Lakes.

——— Notes on the origin and history of the Great Lakes of North America: Proc. Am. Assoc. Adv. Sci., vol. 37, 1889, pp. 197–199.

Discusses same subjects as the last-cited paper.

——— High continental elevation preceding the Pleistocene period: Bull. Geol. Soc. America, vol. 1, 1890, pp. 65–70.

Cites the Great Lakes depressions and deep canyons near the continental border in support of high elevation.

——— Ancient shores, bowlder pavements, and high-level gravel deposits in the region of the Great Lakes: Bull. Geol. Soc. America, vol. 1, 1890, pp. 71–86.

Discusses characteristics of ancient shore lines in the Great Lakes region, bowlder pavements and fringes on lake borders and valley slopes, gravel deposits under the till (termed "buried beaches"), unclassified buried gravels (so-called osars and kames), other ridges thought to be beaches, and gravel plains.

——— Origin of the basins of the Great Lakes of North America: London Quart. Jour. Geol. Soc., vol. 46, 1890, pp. 523–531.

Reiterates views expressed in 1882 and gives a few additional data.

——— Deformation of the Algonquin beach and birth of Lake Huron: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 12–21.

Describes a beach which appears on the borders of Lakes Huron, Michigan, and Superior, and names it the Algonquin. Briefly considers the differential uplift and changes of outlet which it has experienced.

——— High-level shores in the region of the Great Lakes and their deformation: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 201–211.

Describes the several beaches bordering the Huron-Erie basin from the Forest up to the Maumee and notes the amount of warping they have undergone. Refers to "higher coast lines" preceding the Maumee, but thinks some of these may be kames and osars and that all need further investigation.

——— Post-Pliocene continental subsidence versus glacial dams: Bull. Geol. Soc. America, vol. 2, 1891, pp. 465–476.

Notes the evidence of recent occupancy by water at higher levels than the present Great Lakes; considers glacial dams less likely to have caused the retention of waters than a depression to sea level.

——— A review of the history of the Great Lakes: Am. Geologist, vol. 14, 1894, pp. 289–301.

Treats briefly the several topics discussed in his earlier papers, with references to the work of other investigators.

——— The geological survey of the Great Lakes: Proc. Am. Assoc. Adv. Sci., vol. 43, 1895, pp. 237–243.

Similar in scope to last paper.

——— How the Great Lakes were built: Pop. Sci. Monthly, vol. 49, 1896, pp. 157–172.

Similar in scope to last two papers.

——— An account of the researches relating to the Great Lakes: Am. Geologist, vol. 21, 1898, pp. 110–123.

Similar in scope to last three papers, though dealing more especially with what each writer has contributed.

——— The Falls of Niagara: Rept. Geol. Survey Canada for 1905, pub. 1907, 490 pp., 43 pls., 30 figs.

Considers the water power and rate of recession and the various topographic and geologic features along the gorge that have affected the recession; also the variations in the volume of water occasioned by the discharge of the upper lakes at certain times by other outlets than Niagara, and the tilting that has deflected the discharge to Niagara.

Spencer, J. W., L'évolution des chutes du Niagara: La Géographie, vol. 22, 1910, pp. 105–115.

Briefly treats the history of the Great Lakes basins, the work of the falls, and their probable duration. For the first time admits that glacial dams are a factor in the history and development of the Great Lakes.

——— Relation of Niagara River to the glacial period: Bull. Geol. Soc. America, vol. 21, 1910, pp. 433–440.

Thinks that St. Davids buried channel leading northwest from the whirlpool, referred by some geologists to an interglacial Niagara, is preglacial, since it contains a remarkably full series of glacial and interglacial beds, the earliest of which seems likely to be at least as old as the Illinoian drift.

——— Relative work of the Falls of Niagara: Bull. Geol. Soc. America, vol. 21, 1910, pp. 441–446.

Computes the recession more precisely than earlier students, but does not greatly modify earlier results. Places the mean annual rate of recession of the American fall at 0.27 foot and of the Canadian fall at 4.2 feet.

——— Interruption in the flow of the Falls of Niagara in February, 1909: Bull. Geol. Soc. America, vol. 21, 1910, p. 447.

Gives photographs to show a great reduction in volume due not to an ice jam but to the anchoring of ice in a low-water stage in very cold weather.

——— On the focus of postglacial uplift north of the Great Lakes: Jour. Geology, vol. 19, 1911, pp. 57–60.

Shows, by combining triangles in the region of uplift bordering Lake Ontario and Georgian Bay, that the uplift converges to a focus in about latitude 49° N. and longitude 76° W.

——— Postglacial earth movements about Lake Ontario and the St. Lawrence River: Bull. Geol. Soc. America, vol. 24, No. 2, 1913, pp. 217–228, 1 fig. (map), pp. 714–715.

——— Relationship of the Great Lake basins to the Niagara limestone: Bull. Geol. Soc. America, vol. 24, No. 2, 1913, pp. 229–232, 1 fig. (map).

——— Relationship between terrestrial gravity and observed earth movements of eastern America: Am. Jour. Sci., 4th ser., vol. 35, 1913, pp. 561–573, 1 map.

——— Postglacial changes of level versus recent stability of the Lake region of America: Rept. British Assoc. Adv. Sci., Eighty-second Meeting, 1913, pp. 476–477.

——— Outline of the evolution of the Falls of Niagara; contrast with the falls of the Zambesi (private publication), 1913, 8 pp., 2 pls. (map).

Stimson, William, On the deep-water fauna of Lake Michigan: Am. Naturalist, vol. 4, 1871, pp. 403–405.

Records the occurrence of marine crustaceans in the deep part of Lake Michigan; mentions absence of marine shells in the beaches of the lake; suggests that the lake communicated with the ocean in such a way that salt water invaded the lower portion while the surface waters were sufficiently fresh to permit the existence of lacustral species of mollusks. See also P. R. Hoy.

Stuntz, G. R., On some recent geological changes in northeastern Wisconsin: Proc. Am. Assoc. Adv. Sci., vol. 18, 1870, pp. 206–207.

Suggests a differential elevation in the Great Lakes region with northeastward uplift. See also Gilbert and Moseley.

Sutton, George, The gold-bearing drift of Indiana: Proc. Am. Assoc. Adv. Sci., vol. 30, 1882, pp. 177–185.

Notes gold in Dearborn, Ohio, Ripley, Jennings, Jackson, Brown, Morgan, Montgomery, and Warren counties, Ind. Thinks ice moved northwest to southeast, scattering the gold through these counties, a view which is out of harmony with the evidence from moraines and other features.

Taylor, A. E., Road materials of portions of central and eastern Indiana: Thirtieth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1905, pp. 315–356, 359–387, 389–437, 439–496, 501–570. Road materials of southwestern Indiana: Thirtieth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1905, pp. 969–970, 974–975, 981–982, 986–987, 990–1001.

Each paper discusses briefly, county by county, the occurrence of workable deposits of gravel, the limestone, and other sources of road material.

Taylor, F. B., The highest old shore line on Mackinac Island: Am. Jour. Sci., 3d ser., vol. 43, 1892, pp. 210–218.

Describes highest old beach on island and near mainland and recognizes it as Spencer's Algonquin Beach. Classifies beaches as earlier, faint, and fragmentary in southern part of Great Lakes basins, and later, stronger, and continuous in northern part, all being inclined to south more or less. Ascribes former to ice-dammed lakes, latter to marine submergence.

——— A reconnaissance of the abandoned shore lines of Green Bay [Michigan and Wisconsin]: Am. Geologist, vol. 13, 1894, pp. 316–327.

Describes old beaches between Sheboygan, Wis., and north end of Green Bay in Michigan. The shores rise to the north.

——— A reconnaissance of the abandoned shore lines of the south coast of Lake Superior: Am. Geologist, vol. 13, 1894, pp. 365–383.

Describes old beaches between Sault Ste. Marie and Duluth. Suggests name "Nipissing" for lowest and strongest. Regards, probably wrongly, the gravel deposits back of Marquette, 590 feet above the lake, as a beach. Says beach back of Houghton at 410 feet is probably the Algonquin. Supposes Nipissing beach to pass below lake level at Duluth.

TAYLOR, F. B., The limit of postglacial submergence in the highland east of Georgian Bay: Am. Geologist, vol. 14, 1894, pp. 273–289.

Describes beach which defines upper limit of submergence between Barrie and Trout Creek, Ontario, identifies it as Algonquin, and estimates its age (by laminated clay in deltas) at not less than 2,500 years. Regards it (wrongly) as marine and as correlative of upper marine deposits in the lower St. Lawrence Valley.

——— The ancient strait at Nipissing: Bull. Geol. Soc. America, vol. 5, 1894, pp. 620–626.

Gives descriptive details of beaches near North Bay, Ontario, on Lake Nipissing. Thinks the higher ones mark marine waters (a view now abandoned). Traces the lowest or Nipissing over a col to Trout Lake into head of temporary outlet of upper Great Lakes to Ottawa River.

——— Changes of level in the region of the Great Lakes in recent geological time: Am. Jour. Sci., 3d ser., vol. 49, 1895, pp. 69–71. (Letter in reply to J. D. Dana.)

Discusses marine hypothesis of northern beaches. Later abandons views favoring marine origin. (See letter to Am. Geologist, vol. 17, 1896.)

——— The Munuscong Islands (Michigan): Am. Geologist, vol. 15, 1895, pp. 24–33.

Says that hills north of Hessel, Mich., showed as small islands in Lake Algonquin. Gives details of beaches near Gros Cap and on Mackinac Island. Shows rate of rise of Nipissing and Algonquin beaches from Petoskey to Sault Ste. Marie.

——— The second Lake Algonquin: Am. Geologist, vol. 15, 1895, pp. 100–120, 162–179.

Discusses the lakes bounded by the Nipissing Beach and gives a history of the changes of altitude of its plane, based on data of the preceding reconnaissances. [The name "second Lake Algonquin" was replaced later by "Nipissing Great Lakes."] Gives quite fully the facts relating to Nipissing Beach as then known. Discusses change of outlet from North Bay, Ontario, to Port Huron, Mich., and its effect on history of St. Marys, St. Clair, Detroit, and Niagara rivers. Says this epoch of the lakes was synchronous with the maximum of marine Champlain submergence in the lower St. Lawrence. Entertains hypothesis of marine origin for higher northern beaches.

——— Sketch of the Quaternary history of the Great Lakes: Public Occurrent, weekly, Fort Wayne, Ind., vol. 1, No. 2, Dec. 14, 1895.

Gives a popular account of the Great Lakes, embodying the results of a reconnaissance on north coast of Lake Superior in 1895 disproving existence of straits to Hudson Bay. Includes also results of reconnaissance of the Mattawa and Ottawa valleys in which the last position of the ice dam holding Lake Algonquin was found. First uses name "Nipissing Great Lakes."

——— The Nipissing beach on the north Superior shore: Am. Geologist, vol. 15, 1895, pp. 304–314.

Reviews and discusses A. C. Lawson's "Sketch of abandoned strands of Lake Warren." Finds that Nipissing Beach rising to northeast is recognizable in Lawson's descriptions.

——— Preliminary notes on studies of the Great Lakes made in 1895: Am. Geologist, vol. 17, 1896, pp. 253–257.

Gives brief summary of results of reconnaissance of north coast of Lake Superior and of Mattawa and Ottawa valleys. States reasons for final rejection of marine hypothesis of northern beaches of upper lakes, which had been held up to this time. Finds evidences in the Ottawa Valley of ice dam which held Lake Algonquin and of rush of waters where outlet opened through this valley.

——— Notes on the Quaternary geology of the Mattawa and Ottawa valleys: Am. Geologist, vol. 18, 1896, pp. 108–120.

Gives additional details of glacial history of the two valleys.

——— Correlation of Erie-Huron beaches with outlets and moraines in southeastern Michigan: Bull. Geol. Soc. America, vol. 8, 1897, pp. 313–317.

Describes Imlay and Ubly outlets and eastern part of Grand River outlet. Shows relations of the several beaches and moraines to these and to other less important spillways, and discusses character of water-laid moraines. Introduces names of Lake Whittlesey, Lake Saginaw, and Duplain Beach, and limits name of Lake Warren.

——— A short history of the Great Lakes: Dryer's Studies in Indiana geography, pp. 90–110, Inland Pub. Co., Terre Haute, 1897.

Discusses in popular form changes of outlet, altitude, area, and depth in the glacial lakes incident to the recession of the ice sheet. Discusses also the relation of lake history to Niagara Falls and to the Champlain marine submergence in the lower St. Lawrence Valley.

——— Moraines of recession and their significance in glacial theory: Jour. Geology, vol. 5, 1897, pp. 421–466.

Notes existence of 15 moraines of recession of Wisconsin age between Cincinnati and Mackinac. Discusses their theoretical significance and the light they throw on the behavior of the ice sheet. Argues that the position of water-laid moraines shows that ice lobes stood with solid fronts in lakes and calved few icebergs. Data have been slightly modified by later investigations, the time found for glacial recession being probably too great.

——— The Nipissing-Mattawa River, the outlet of the Nipissing Great Lakes: Am. Jour. Sci., 4th ser., 1897, pp. 208–218. Abstract in Am. Geologist, vol. 20, 1897, pp. 65–66.

Describes a recent great river in the Mattawa Valley. Conditions of erosion showed to be in some respects exceptional, but time allowed for its work is probably too long.

TAYLOR, F. B., Notes on the abandoned beaches on the north coast of Lake Superior: Am. Geologist, vol. 20, 1897, pp. 111–128. Gives details of reconnaissance made in 1895. Identifies Nipissing beach and shows it rising to the northeast. The Algonquin beach, doubtfully identified, appears to be nearly horizontal.

——— The Champlain submergence and uplift, and their relations to the Great Lakes and Niagara Falls (abstract): Rept. British Assoc. Adv. Sci. for 1897, pp. 652–653.

Discusses interrelations generally and with special reference to their bearing on the history of Niagara Falls.

——— Some features of the recent geology around Detroit (abstract): Proc. Am. Assoc. Adv. Sci., vol. 46, 1898, pp. 201–202.

Gives details of old beaches, moraines, and river conditions around Detroit. Discusses drowned condition of tributaries of St. Clair-Detroit River and of the west end of Lake Erie.

——— The great ice dams of Lakes Maumee, Whittlesey, and Warren: Am. Geologist, vol. 24, 1899, pp. 6–38.

Discusses the lakes named, with special reference to proofs of existence of the great ice dams which retained them.

——— Surface geology of Lapeer County, Mich.: Rept. State Board Geol. Survey Michigan for 1901, pp. 109–117.

Gives sketch of surface geology based on unfinished field work. Maps moraines and glacial drainage, including Imlay outlet, in the region of the reentrant angle between the Huron and Saginaw lobes.

——— Relation of Lake Whittlesey to the Arkona beaches: Seventh Ann. Rept. Mich. Acad. Sci., 1905, pp. 29–36.

Argues that features in St. Clair County, Mich., show that the Arkona beach or beaches antedate the Belmore, though at a lower level, and that a readvance of the ice marked by the Port Huron morainic system raised the lake level and formed Lake Whittlesey, whose discharge was through the Ubly outlet.

——— Pleistocene deposits of southwestern Ontario: Summary Rept. Canada Geol. Survey, 1908, pp. 102–111; 1909 pp. 164–167.

Gives results of leveling and incidental investigations on Algonquin and Nipissing beaches made with assistance of J. W. Goldthwait, R. C. Jacobson, and W. A. Johnston. The 1909 report describes the glacial formations in the central part of the peninsula and in an area on the north shore of Lake Erie between Simcoe and the mouth of Grand River.

——— A review of the Great Lakes history with special reference to the deformation of the ancient water planes (abstract): Science, vol. 27, 1908, pp. 725–726.

Chiefly considers the deformation in the beaches of the Michigan and Huron basins, which has since been largely worked out by spirit leveling; considers other basins briefly.

——— Study of ice-sheet erosion and deposition in the region of the Great Lakes (abstract): Bull. Geol. Soc. America, vol. 22, 1911, p. 727.

Shows glacial erosion of unweathered rock to be very slight. Distribution of thick drift controlled partly by topography.

——— The glacial and postglacial lakes of the Great Lakes region: Ann. Rept. Smithsonian Inst., 1912, pp. 291–327, 10 figs., 1913.

Advance publication of Chapter XII of this monograph.

——— Niagara Falls and Gorge: Guide Book Twelfth Internat. Geol. Cong. No. 4 (issued by the Canada Geol. Survey), 1913, pp. 8–70, 2 maps, 1 pl., figs.

——— Moraines north of Toronto (Ontario): Guide Book Twelfth Internat. Geol. Cong. Guide No. 6 (issued by Canadian Geol. Survey), 1913, pp. 35–42, 3 figs.; Twenty-second Ann. Rept. Ontario Bur. Mines, pt. 1, 1913, pp. 256–260.

——— The moraine systems of southwestern Ontario: Trans. Canadian Inst., vol. 10, pt. 1, 1913, pp. 57–79, 4 pls., 4 maps.

Mainly a descriptive list of moraines and related ice-border drainage channels. Covers nearly all of southwestern peninsula.

——— Characters of the older sections of the Niagara gorge and their correlation with Great Lakes history (abstract): Bull. Geol. Soc. America, vol. 24, No. 4, 1913, pp. 72–73.

——— Map of the old distributaries of the St. Clair and Detroit rivers (abstract): Fourteenth Rept. Michigan Acad. Sci., 1912, p. 142.

——— and KINDLE, E. M., Description of the Niagara quadrangle [New York]: Niagara folio (No. 190), Geol. Atlas U. S., U. S. Geol. Survey, 1913, 25 pp., 25 pls., 4 maps, 16 figs.

Includes brief history of upper lakes from the time of Early Lake Algonquin. History divided into five stages which are precise correlatives of five sections of Niagara gorge, as shown by variations of width and depth of gorge arising from large changes of volume. Shows good basis for time estimates which apply to the lakes as well as to Niagara.

THOMPSON, MAURICE, Glacial deposits of Indiana: Fifteenth Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1886, pp. 44–56.

Discusses glacial action, surface features, and drift deposits, and gives evidence obtained from sections and borings.

——— A terminal moraine in central Indiana: Fifteenth Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1886, pp. 57–60.

Discusses a belt of thick drift leading eastward from Benton and Warren counties across the State to Randolph and Wayne counties.

THOMPSON, MAURICE, Drift beds of Indiana: Sixteenth Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1888, pp. 20–40.

After noting the complexity of drift deposits suggests that they have experienced marked postglacial modification. Discusses the depth and structure of the drift mass and the bearings of striæ.

——— Gold, silver, and precious stones: Sixteenth Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1888, pp. 87–92.

Mentions that the only mode of occurrence is in drift specimens.

——— Formation of soil and other superficial deposits: Sixteenth Rept. Geol. Survey Indiana, 1888, pp. 93–97.

Gives special attention to the accumulation of marl, which he thinks has been carried by percolating waters into the drift basins.

——— Report on Carroll County: Seventeenth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1891, pp. 172–176, 186.

Touches briefly on topography, soils, and glacial deposits.

THOMPSON, W. H., Reports briefly on glacial deposits in the following counties of Indiana: Clinton, Marshall, and Starke counties: Fifteenth Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1886, pp. 154–159, 221–227; Pulaski and White counties: Sixteenth Rept., 1888, pp. 137–154.

——— and LEE, S. E. See Lee and Thompson.

TRANSEAU, E. N., The bogs and bog flora of the Huron River valley, Michigan: Bot. Gazette, vol. 40, 1905, pp. 351–375, 418–448; vol. 41, 1906, pp. 17–42.

Discusses the relation of the bogs to the physiographic features and drainage conditions and the causes for floral characteristics.

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UPHAM, WARREN, The fiords and Great Lake basins of North America as evidence of preglacial continental elevation, etc.: Bull. Geol. Soc. America, vol. 1, 1890, pp. 563–567.

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——— Relationship of the glacial lakes Warren, Algonquin, Iroquois, and Hudson-Champlain: Bull. Geol. Soc. America, vol. 3, 1892, pp. 484–497.

——— Late glacial or Champlain subsidence and reelevation of the St. Lawrence River basin: Am. Jour. Sci., 3d ser., vol. 49, 1895, pp. 1–18; also Twenty-third Rept. Geol. and Nat. Hist. Survey Minnesota, 1895, pp. 156–193.

Discusses the evidence of uplift and subsidence as shown by beaches in the St. Lawrence basin.

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——— Departure of the ice sheet from the Laurentian lakes: Bull. Geol. Soc. America, vol. 6, 1895, pp. 21–27.

Attempts to correlate the shore lines of the Superior basin with those of the Huron-Erie basin.

——— Origin and age of the Laurentian lakes and of Niagara Falls: Am. Geologist, vol. 18, 1896, pp. 169–177.

Discusses the preglacial condition of the St. Lawrence basin, the changes which brought on the ice age, the recession of the ice sheet, and the development of the glacial lakes Warren, Algonquin, and Iroquois; and outlines the history of Niagara Falls.

——— Rhythmic accumulation of moraines by waning ice sheets: Am. Geologist, vol. 19, 1897, pp. 411–417.

Suggests the derivation of moraines chiefly from englacial and superglacial drift and partly from the contemporaneous accumulation of successive moraines. Considers the rhythm of morainal accumulation independent of secular variations of climate and largely dependent on the retardation of the ice movement by englacial drift.

——— Fields of outflow of the North American ice sheet, Twelfth Internat. Geol. Cong., Canada, 1913, 8 pp. (advance copy).

VEATCH, A. C., Notes on the Ohio Valley in southern Indiana: Jour. Geology, vol. 6, 1898, pp. 257–272.

Discusses drainage features, loess, and old gravels, chiefly in Spencer County.

VOLNEY, C. F., A view of the soil and climate of the United States of America, with introduction by C. B. Brown, Philadelphia, 1804.

Describes geology of lake region and Niagara Falls. Regards the bed of Lake Ontario as "the crater of an extinguished volcano" (p. 99).

WALKER, BRYANT, Origin and distribution of land and fresh-water mollusca of North America: First Rept. Michigan Acad. Sci., for 1894-1898, pp. 43-61.

Discusses effect of glaciation on the distribution of mollusks; gives illustrations from the southern peninsula of Michigan and other localities.

——— Distribution of Unionidæ in Michigan, 22 pp., 3 maps, Detroit, 1898.

Shows the distribution of the mollusks in relation to glacial drainage and glacial lakes.

WALLACE, S. J., Lakes and lake regions: Proc. Am. Assoc. Adv. Sci., vol. 19, 1870, pp. 182-185.

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WARD, L. C., Road materials of the northern third of Indiana: Thirtieth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1905, pp. 161-272.

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WARDER, R. B., Surface features and post-Tertiary deposits of Dearborn, Ohio, and Switzerland counties, Ind.: Third and Fourth Ann. Repts. Geol. Survey Indiana, 1871 and 1872, pp. 387-395, 401-413.

Notes the occurrence of soil and timber under glacial deposits.

WHITNEY, J. D., and FOSTER, J. W. See Foster and Whitney.

WHITTLESEY, CHARLES, Report on the geology and topography of a portion of Ohio: Second Ann. Rept. Geol. Survey Ohio, 1838, pp. 41-71.

Records fluctuations of Lake Erie and discusses the encroachment of the lake upon its shore and the lake ridges near the shore.

——— Notes upon the drift and alluvion of Ohio and the west: Am. Jour. Sci., 2d ser., vol. 5, 1848, pp. 205-217.

Separates the drift deposits into blue and yellow hardpan, sand and gravel, valley drift, lacustrine deposits, bowlders, and alluvion. Notes occurrence of buried timber and glacial striæ.

——— On the natural terraces and ridges of the country bordering Lake Erie: Am. Jour. Sci., 2d ser., vol. 10, 1850, pp. 31-39.

Deals mainly with old beaches south of Lake Erie. Says lake ridges and terraces are restricted to levels 240 feet or less above Lake Erie and thinks that "ancient currents" acted at higher levels.

——— On the ancient and present beaches of Lake Michigan: Foster and Whitney's Lake Superior, pt. 2, 1851, pp. 174-176, 270-273.

Describes certain low beaches scarcely 20 feet above Lake Michigan.

——— On the superficial deposits of the northwestern part of the United States: Proc. Am. Assoc. Adv. Sci., vol. 5, 1851, pp. 54-59.

Describes briefly the lacustral deposits about the Laurentian lakes and argues that the blue clays of the Lake Erie basin and the red clays of the Lake Michigan and Lake Superior basins are synchronous.

——— Superficial deposits south of Lake Superior: Owen's report on Wisconsin, Iowa, and Minnesota, Philadelphia, 1852, pp. 425-429.

Discusses the features and deposits resulting from glaciation and lake occupancy, and considers the clays to be fresh-water deposits.

——— On the drift cavities or potash kettles of Wisconsin: Proc. Am. Assoc. Adv. Sci., vol. 13, 1860, pp. 297-301.

Refers kettles or basins in sand plains to the melting of fragments of ice inclosed in and buried beneath drift materials.

——— On the ice movement of the glacial era in the valley of the St. Lawrence: Proc. Am. Assoc. Adv. Sci., vol. 15, 1867, pp. 43-54.

Discusses glacial deposits and striæ and states that the drift from the east end of Lake Ontario to the Lake of the Woods appears to be of fresh-water origin.

——— Fresh-water glacial drift of the northwestern states: Smithsonian Contr., vol. 15, 1867, 38 pp.

Reviews the evidence in favor of fresh-water origin of certain clays and lake ridges.

WILDER, H. J., and GEIB, W. J. See Geib and Wilder.

WINCHELL, ALEXANDER, The shell marls of Michigan: Michigan Farmer, September, 1855, pp. 257-259. (Not examined.)

——— Superficial deposits of Michigan and Alabama. Harper's Geol. Rept. of Mississippi, 1857, pp. 316-318. (Not examined.)

——— Outlines of the geology of Michigan: Michigan Farmer, December, 1858. (Not examined.)

——— Geology of Michigan. Lansing, 1861, pp. 127-133.

Discusses the surface geology.

WINCHELL, ALEXANDER, On the origin of the prairies of the valley of the Mississippi: Am. Jour. Sci., 2d ser., vol. 38, 1864, pp. 332–344.

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——— Some indications of the northward transportation of drift materials of the lower peninsula of Michigan: Am. Jour. Sci., 2d ser., vol. 40, 1865, pp. 331–338.

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——— Soils and subsoils of Michigan, 1865, 30 pp. By order of legislature.

Discusses general geology of soils, including drift agencies; gives especial attention to the peaty and prairie soils and dunes and to the effect of drainage and the removal of forests.

——— The Grand Traverse region, Ann Arbor, 1866, 97 pp. and map.

Discusses hydrography, topography, soil, climate, plants, animals, general geology, crops, fruits, industries, settlements, highways, and paleontology.

——— The fruit-bearing belt of Michigan: Proc. Am. Assoc. Adv. Sci., vol. 15, 1866, pp. 84–91.

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——— Peat in Michigan: Leavitt's Peat Journal, vol. 1, 1867. (Not examined.)

——— The bowlder of 1869: University Magazine, May, 1869, p. 4.

Discusses the source of red jasper conglomerate bowlders.

——— Geology of Berrien County, Mich.: Directory of Berrien County, February, 1871, pp. 21–26.

Discusses general geology, soils, dunes, and artesian-well prospects.

——— The soils and geological features of Michigan: The Traveller, London, England, 1871. (Not examined.)

——— Diagonal system in the physical features of Michigan: Am. Jour. Sci., 3d ser., vol. 6, 1873, pp. 36–40.

Considers the features the resultant of a glacial force (acting from the northeast) and of the stratigraphic conditions (or course of strike).

——— Rectification of the geological map of Michigan: Proc. Am. Assoc. Adv. Sci., Detroit meeting, 1875, pp. 27–43.

Outlines places of rock outcrop on borders of the State and presents numerous observations on the drift, including several well records.

——— Supposed agency of ice floes in the Champlain period: Am. Jour. Sci., 3d ser., vol. 11, 1876, pp. 225–228.

Pictures a way by which blocks of Carboniferous limestone found in the drift in Oceana County might have been transported thither by an ocean current.

——— Michigan.

Presents a condensed popular sketch of the topography, climate, and geology of the State, extracted from Walling's Atlas of Michigan, 1879. An earlier and briefer discussion of these topics was presented in Harper's Magazine for July, 1871.

——— Geology of Washtenaw County: County History, published by C. C. Chapman & Co., Chicago, 1881, pp. 141–172.

Describes large "Corniferous" limestone blocks and classifies the bowlders found in the drift. Discusses the topographic features of the county. Describes position and height of lake ridges in the southeastern part.

——— A series of popular works touching incidentally on features of Michigan, namely: Sketches of creation, Harper's, New York, 1870; Sparks from a geologist's hammer, S. C. Griggs & Co., Chicago, 1881; Geological excursions, S. C. Griggs & Co., Chicago, 1884; Walks and talks in the geological field, Chautauqua Press, New York, 1886; Geological studies, S. C. Griggs & Co., Chicago, 1886.

——— On the geology of Ann Arbor: Am. Jour. Sci., 3d ser., vol. 30, 1885, p. 315.

Brief abstract of a paper read at the meeting of the American Association for the Advancement of Science at Ann Arbor in 1884. Describes the leading topographic features.

WINCHELL, A. N., The age of the Great Lakes of North America: Am. Geologist, vol. 19, 1897, pp. 336–339.

Gives a partial bibliography with brief notes.

WINCHELL, N. H., The glacial features of Green Bay, of Lake Michigan, with some observations of a probable former outlet of Lake Superior: Am. Jour. Sci., 3d ser., vol. 2, 1871, pp. 15–19.

Notes the expansion of an ice tongue into Green Bay and describes a drift-filled lowland from Lake Superior through Little Bay de Noc that is considered an old outlet of the Lake Superior basin.

——— The drift deposits of the northwest: Pop. Sci. Monthly, vol. 3, 1873, pp. 202–210, 286–297.

Presents the several theories in reference to the origin of the drift and sums up the evidence in favor of the glacial theory.

——— Vegetable remains in the drift deposits of the northwest: Proc. Am. Assoc. Adv. Sci., vol. 24, 1876, pt. 2, pp. 43–56.

Summarizes the occurrence of vegetable deposits between the drift sheets or in the midst of the drift in the several Northwestern States, from Ohio to Minnesota.

WOOLDRIDGE, C. W., Recent geological changes in western Michigan: Pop. Sci. Monthly, vol. 24, 1884, pp. 826–830.

Notes a change of 6 feet in the level of White Lake and interprets it to be a local land oscillation instead of a variation in the height of the water that backs into the lake from Lake Michigan.

WOOLDRIDGE, C. W., The river-lake system of western Michigan: Am. Geologist, vol. 1, 1888, pp. 143-146.

Notes that the lakes lie in channels bordered by till bluffs and are therefore not inclosed entirely by drifting sand. Interprets postglacial history to include a stage when the water stood markedly lower than now, during which deep valleys were cut on the east shore of Lake Michigan. Thinks this was followed by a stage when the water stood higher than now and beaches were formed above the level of the present lake.

——— The postglacial geology of Ann Arbor, Mich.: Am. Geologist, vol. 2, 1888, pp. 35-39.

Notes the topographic features around Ann Arbor and describes certain gravel pits which are thought to exhibit the structure of an ancient delta, and argues therefore that Ann Arbor is situated in a former bay covered by Lake Erie. In a footnote announces the discovery of shore lines at two levels passing through Ann Arbor, the upper corresponding with an outwash apron on which the university campus is built, and the lower with a valley which connects Huron and Saline rivers. Both are found by Leverett's observations to be above the highest level of Lake Maumee and are referable to glacial outwash and glacial drainage instead of to the shore phenomena of a lake.

WOOSTER, L. C., Kames near Lansing, Mich.: Science, vol. 3, 1884, p. 4.

Contains a brief discussion of the Mason esker.

WRIGHT, G. F., Explorations of the glacial boundary between New Jersey and Illinois: Proc. Am. Assoc. Adv. Sci., vol. 32, 1883, pp. 202-208.

Notes the great northward reentrant in the glacial boundary in Indiana as well as other irregularities, and is inclined to refer them to the combined effect of difference in level and the relation to gathering grounds of snow. Announces the hypothesis of the Cincinnati ice dam.

——— The glacial boundary in Ohio, Indiana, and Kentucky: Western Reserve Hist. Soc., Cleveland, 1884, 86 pp.

Discusses in detail the drift features along the glacial boundary in the States named.

——— The ice age in North America and its bearing on the antiquity of man, New York, 4th ed., with supplementary notes, 1896, pp. vii-xxv, 315-358.

Discusses the Great Lakes region and makes incidental references to the glacial features and deposits of Indiana and Michigan. Gives important recent contributions in the preface.

——— The glacial boundary in western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois: Bull. U. S. Geol. Survey No. 58, 1890, pp. 39-110.

Discusses in detail the drift features along the glacial boundary in the States named; revises to some extent the position of boundary given in earlier papers.

——— Outlets of the Great Lakes: The Nation, vol. 55, 1892, pp. 217-219.

Gives a popular account of the former extent of the Great Lakes; describes especially the Mattawa outlet from Georgian Bay and Lake Nipissing to Ottawa River.

——— Man and the glacial period, New York, 1892, pp. vii, 385.

Presents many data which bear upon glacial history and the history of the Great Lakes.

CHAPTER II.

PHYSICAL FEATURES.

By Frank Leverett.

The region embraced in this monograph includes the deep basins of Lakes Michigan and Huron as well as the country between them and its southward continuation to the glacial boundary. These basins and their bordering lowlands controlled the courses of glacial movement to a marked degree, while the highlands between the basins checked the flow of the ice and gave it a lobate border.

TOPOGRAPHY.

ALTITUDE.

MICHIGAN.

The greater part of the bed of Lake Michigan lies between 300 feet above and 300 feet below sea level, a narrow strip, trending north and south about in the direction of the axial movement of the ice from latitude 44° 20′ to latitude 44° 40′, reaching the latter depth.

In the Huron basin, where only a few square miles are down to sea level, the deep portion trends northwest and southeast nearly at a right angle to the general direction of ice movement from the Labrador center; it lies, however, more nearly in line with the probable course of ice movement from the high land north of Lake Superior at an early stage of glaciation. Saginaw Bay, the large southwest arm of Lake Huron, although in the line of axial movement from the Labrador center, is a very shallow body of water, its bed being more than 500 feet above sea level. The strong flow of ice through the Saginaw basin was probably induced by topographic conditions on the eastern side of Lake Huron. Ice moving into the Lake Huron basin from Georgian Bay would naturally have passed on directly into the Saginaw basin.

The altitude of the rock surface in Michigan is greatest in a strip leading from the "thumb," or Huron-Saginaw upland, southwest toward the corners of Michigan, Indiana, and Ohio. The culminating points, situated in Jackson and Hillsdale counties, exceed 1,100 feet above sea level, and the drift knolls there reach nearly 1,300 feet. This high tract formed the belt of separation between the Saginaw and Huron-Erie ice lobes. The rock surface maintains a high altitude southward only to the southern part of Hillsdale County, Mich., but a prominent belt of very thick drift, rising above the 1,000-foot contour, continues southwestward for some distance into northeastern Indiana. It was heaped up between the Saginaw and Huron-Erie lobes.

On the northwest border of the Saginaw basin is an elevated tract, the Michigan-Saginaw upland, which embraces the highest points of the drift surface in the southern peninsula. As shown by the contours of the topographic map[1] of Michigan (Pl. I) about one-fourth of the area north of latitude 44° has an altitude between 1,100 and 1,200 feet, and one-fourth has an altitude of 1,200 to 1,700 feet. The descent from 1,100 to 900 feet is abrupt, giving the area between 1,100 and 1,200 feet a shelf-like or table-land appearance. This shelf, however, is not due to the configuration of the underlying rock, for so far as known the rock in this region nowhere rises 900 feet above sea level; it is a great accumulation of drift, averaging perhaps 400 feet in depth, which was banked up between the converging ice lobes from the Michigan, the northern Huron, and the Saginaw basins.

[1] First published in Water-Supply Paper U. S. Geol. Survey No. 182.

The average altitude of the entire southern peninsula of Michigan (not including the beds of the Great Lakes) is estimated to be 835 feet. The range in altitude is from 573 to 1,710 feet. The highest points are morainic knobs a few miles southeast of Cadillac in Sherman Township, Osceola County, and the lowest are on the border of Lake Erie. As planimeter measurements of the bedrock contours (see Pl. II) made by W. F. Cooper, of the Michigan Geological Survey, show an average altitude of 554 feet, an average thickness of nearly 300 feet of drift is indicated. The bedrock ranges from a little below sea level to fully 1,100 feet above.

INDIANA.

The average altitude of Indiana has been estimated by Gannett[1] to be 700 feet and by Gorby[2] to be 800 feet; the estimate by Gorby, being based more largely on field observations, is perhaps the closer approximation. The altitude ranges from 314 feet at the mouth of the Wabash to 1,285 feet on the morainic hills in southern Randolph County.

Outside of the prominent drift belt in the northeastern counties only one large area in Indiana rises above 1,000 feet. This is in the eastern part of the State, chiefly in Wayne and Randolph counties, and is due to the rock surface, which reaches fully 1,100 feet and bears morainic knolls that rise above 1,200 feet. It is in this area that the reentrant between the Miami and East White lobes is found. Only here and in the "thumb" of Michigan do rock elevations seem to have had much influence on ice movements; the low basins now occupied by the Great Lakes were the features which had greatest control.

In northern Indiana and in nearly all of the southern peninsula of Michigan the rock surface is entirely concealed beneath the thick glacial deposits. In southern Indiana, however, a succession of rock formations from the Ordovician to Pennsylvanian is exposed from east to west. (See Pl. III.) These formations trend from west of north to east of south about parallel to the western or main branch of the Cincinnati axis. As they vary greatly in their power to resist weathering and erosion, they have given rise to a series of troughs or basins separated by ridges and highlands. These, however, have exerted but little influence on the flow of the ice or the outline of the ice border.

The hills in the more resistant formations rise to a somewhat regular elevation that suggests a peneplain, and a few hills in the softer formations reach nearly the same altitude. Most of the divides in the friable rocks of the southwestern part of the State, however, are 50 to 150 feet lower than the level of the suggested peneplain, and only isolated hills rise to its level. Some of the hills of friable rock carry deposits of bronzed gravel, presumably of Tertiary age, that antedate the erosion of the formation elsewhere; for example, two hills north of Princeton, Ind., some knobs bordering White River near Shoals, and other knobs in Washington County[3] carry a little bronzed gravel similar to the Tertiary gravel of southern Illinois.

RELIEF.

INDIANA.

Throughout much of the drift-covered portion of Indiana the surface is monotonously smooth, both on slopes of 10 to 20 feet to the mile and on nearly dead-level surfaces. Many moraines also are inconspicuous.

Sharply morainic tracts with prominent knob and basin topography are found mainly in three localities. The largest and most prominent is in the northeastern part of the State and covers a considerable part of Steuben, Lagrange, Noble, and Kosciusko counties and parts of Dekalb, Whitley, Wabash, Miami, and Fulton counties. In this tract are many knolls 30 to 50 feet high and a few 75 to 100 feet or more; among them are numerous basins containing lakes and marshes. The second large morainic tract sweeps around the head of Lake Michigan

[1] Gannett, Henry, Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1893, p. 289.
[2] Gorby, S. S., Sixteenth Rept. Dept. Geology and Nat. Hist. Indiana, 1891, p. 217.
[3] Cox, E. T., Third Rept. Geol. Survey Indiana, 1872, p. 138. Leverett, Frank, Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1897, p. 433; also Mon. U. S. Geol. Survey, vol. 41, 1902, p. 111. Fuller, M. L., and Ashley, G. H., Ditney folio (No. 84), Geol. Atlas U. S., U. S. Geol. Survey, 1902, p. 6. Blatchley, W. S., Thirtieth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1905, p. 936.

and fills much of the interval between the lake and the Kankakee marsh. Its knolls rarely reach 50 feet in height, but they are closely aggregated and so interspersed with basins that the expression is in striking contrast to the bordering plains. The third area is in southern Randolph, southeastern Delaware, and northern Henry counties, in the reentrant between the East White lobe and the Miami lobe. As already noted, this reentrant occurs in the highest part of Indiana, where the altitude was influential in preventing the extension of the ice so far south as on bordering lower tracts. The area, which is 6 to 10 miles wide and 30 miles long, is not only filled with sharp knolls inclosing deep basins and sloughs but is also thickly strewn with bowlders.

The morainic tracts mentioned were formed at the last or Wisconsin stage of glaciation. The exposed surface of the older or Illinoian drift sheet presents only a few developments of ridged drift. Some of these, however, are prominent, reaching a height of 50 to 150 feet, as, for example, Chestnut Ridge in Jackson County and Mount Auburn in Shelby County.

The few eskers in Indiana are but 10 to 25 feet in height and 3 miles or less in length. No drumlins have been observed, and few kames are found outside of the strong morainic belts.

MICHIGAN.

Strong moraines are numerous in the southern peninsula of Michigan. They rival and some of them far exceed the strongest in Indiana, reaching heights of 300 to 400 feet or more. In the southeastern part of the State some of the moraines of the Wisconsin stage override a basal ridge of pre-Wisconsin drift, and possibly they form only the upper part of the high land northwest of the Saginaw basin. The bulk of the drift accumulation may have been developed in pre-Wisconsin stages of glaciation. The plane-surfaced portions of the drift of Michigan are chiefly on the borders of the peninsula and in a broad belt extending southwestward from the Saginaw basin beyond Lansing; the latter, however, is interrupted by a few morainic ridges with gently undulating surface. A considerable part of the plains was covered by glacial lake waters.

Eskers are numerous on the slope that rises toward the south from the Saginaw basin. (See Pls. VIII–XI.) Their height is commonly only 20 to 30 feet, but their very steep sides make them conspicuous.

Drumlins are numerous in Antrim and Charlevoix counties (figs. 2 and 3), and a few are found in Emmet, Cheboygan, and Alpena counties. They range in height from 60 to 70 feet down to barely perceptible ridges.

The lines of glacial drainage and the outlets of the large glacial lakes are conspicuous, some of them being many times the size of the valleys excavated by the postglacial streams. This is very apparent where a stream passes from a modern or postglacial valley into a line of glacial drainage. The shores of the glacial lakes are on the whole inconspicuous, though characteristic enough to have been recognized and traced by pioneer students. The Algonquin and Nipissing shores are much more conspicuous than those of the earlier lakes, and probably those lakes were longer lived.

Sand dunes are conspicuous on the border of Lake Michigan in Lake, Porter, and Laporte counties, Ind., the highest having an altitude of about 200 feet. The wind which formed them derived its material partly from the abandoned shores and beds of the glacial Lake Chicago and partly from the present shore of Lake Michigan. The largest are built up from the present shore, those connected with the shore of Lake Chicago being usually less than 50 feet in height. Low sand ridges 10 to 20 feet high in the Kankakee and Tippecanoe drainage basins in northern Indiana and on the borders of the White, East White, Eel, and Wabash valleys in central and southwestern Indiana, are apparently the product of wind action.

In Michigan sand dunes are prominent along much of the shore of Lake Michigan. They are highest at the river deltas, where many of them rise 200 feet above the lake. A few low dunes occur on the border of Saginaw Bay. Dunes have been formed in places on the sandy outwash plains among the moraines, and sand storms occur even now when high winds sweep across cleared fields in these plains.

DRAINAGE.

LAKES.

INDIANA.

Numerous small lakes in the northern part of Indiana occupy depressions in the drift surface. The largest, Turkey or Wawasee in Kosciusko County, has an area of only 5.66 square miles. Few cover more than 1 square mile. The greatest depth, 121 feet, is found in Tippecanoe Lake in Kosciusko County, but depths of 50 or more feet are found in many others. In the northwest part of the State several shallow lakes are shut in between dune belts or beaches of Lake Michigan and those of its predecessor, Lake Chicago. Numerous shallow ponds and lagoons lie in the alluvial bottoms of the large rivers in the southwestern part of the State. In Dubois County, near Jasper and Ireland, some conspicuous though shallow lakes, having areas of several hundred acres each, stand in the line of preglacial valleys that have been only partly filled by drift deposits. So far as known these are the only lakes in the State that antedate the Wisconsin ice invasion. They are nearly filled by muck and aquatic vegetation and have recently been greatly reduced in area by artificial drainage.

The number of lakes and ponds in the State represented on the county maps in Baskin, Forster & Co.'s State atlas is 683, of which 156 are in the alluvial bottoms and are transitory. Some of those in the depressions of the glacial drift are nearly filled by vegetal growth and some have been drained to a marshy condition by artificial ditches. There remain probably less than 400 which are too deep to be drained. The following table, obtained in large part from the report by Blatchley and Ashley on the lakes and marl deposits of Indiana,[1] gives a list of the more important lakes with their areas, altitudes, and depths:

Lakes of Indiana having an area of 1 square mile or more.

Name.	County.	Area.	Altitude above sea level.	Maximum depth.
		Sq. miles.	*Feet.*	*Feet.*
Turkey or Wawasee	Kosciusko	5.66	862	68
Maxinkuckee	Marshall	2.97	734	89
James	Steuben	2.62	[b] 1,050	87
Wolf [a]	Lake and Cook	2.50	580	14
Bass	Starke	2.23	[b] 720	32
Tippecanoe	Kosciusko	1.61	[b] 850	121
Crooked	Steuben	1.47	...	30
Manitou	Fulton	1.39	[b] 760	49
George	Lake	1.35±	...	...
Lake of the Woods	Marshall	1.25	[b] 825	...
Cedar	Lake	1.17	680	20
Duchemin	Laporte	1.17±	[b] 770	...
Fish	Steuben	1.15	910	68
Little Eagle	Kosciusko	1.10	[b] 850	...
Webster	do	1.06	[b] 875	43

[a] Partly in Cook County, Ill. [b] Determined by barometer.

MICHIGAN.

In the southern peninsula of Michigan lakes are present in every county except three at the head of Saginaw Bay; they are scarce, however, in several other counties in the plain southwest of this bay and in the plain bordering Lakes Erie, St. Clair, and the southern part of Lake Huron. They range in area from a few acres to 31 square miles, the largest being Houghton Lake, in Roscommon County. The number is not known, for in some of the northern counties the best maps yet published represent only a part of them. Many land-survey plats show only those crossed by section or quarter-section lines and give measurements of only a few of those crossed; consequently the outline and extent of few are correctly set forth. The inaccuracies of the land-survey plats have been repeated in county atlases and other maps.

The lakes nearly all occupy depressions in the surface of the glacial deposits, some of them being in the moraines and others in the outwash aprons. Many in the latter areas are without

[1] Twenty-fifth Ann. Rept. Dept. Geology and Nat. Res. Indiana, pp. 31-321, 1901.

surface outlet. The depth of few lakes is known, but that of those in the moraines and outwash aprons appears to be as great as that of lakes of corresponding size in the moraines and outwash aprons of northern Indiana—40 to 100 feet or more. As in Indiana, many of the lakes contain large deposits of marl 40 feet or less in depth. A few lakes along the shore of Lake Michigan are shut in by dunes and are shallow; a few in Monroe County are in sink holes in the limestone; and a few in Alpena and Presque Isle counties are in sink holes or in rock basins. Long and Grand Lakes in the counties last mentioned are situated at the base of rock escarpments but owe their existence, at least in part, to drift obstruction.

The following table contains a list of 81 lakes (all that have an area of a square mile or more), with their approximate altitudes and their areas as estimated from the county maps in the Tackabury atlas. They aggregate 390 square miles and probably embrace half the inland-lake area in the peninsula. Most of the altitudes have been determined by aneroid barometer or estimated from altitudes of neighboring railway stations. A few stand near the level of Lake Michigan and a few, as indicated in the table, have been determined by spirit level.

Lakes in the southern peninsula of Michigan having an area of 1 square mile or more.

Name.	County.	Area.	Altitude above sea level.	Name.	County.	Area.	Altitude above sea level.
		Sq. miles.	*Feet.*			*Sq. miles.*	*Feet.*
Houghton	Roscommon	31	*a b* 1,125	Rush	Huron	2	595
Pine	Charlevoix	29	580	Coldwater	Branch	2	*a* 1,000
Mullet	Cheboygan	28	594	Marble	.....do	1.8	*a* 1,000
Torchlight	Antrim	27	592	Cedar	Alcona	1.5	*a* 595
Burt	Cheboygan	25	596	Manistee	Kalkaska	1.5	*a* 1,185
Black	.....do	18	*a* 615	East Twin	Montmorency	1.5	*a* 1,210
Higgins	Roscommon	15	*a* 1,160	West Twin	.....do	1.5	*a* 1,210
Hubbard	Alcona	13	*a* 700	Grass	Benzie	1.5	*a* 825
Crystal	Benzie	11	585	Big Star	Lake	1.5	*a* 850
Elk	Antrim	10	589	Chippewa	Mecosta	1.5	*a* 1,050
Glen	Leelanau	9	*c* 597	Cass	Oakland	1.5	930
Carp	.....do	8.5	*c* 589	Austin	Kalamazoo	1.5	870
Grand	Presque Isle	8.5	*d* 636	Crooked	Barry	1.5	925
Long	Alpena	8	*d* 690	Diamond	Cass	1.5	880
Muskegon	Muskegon	7	580	Klinger	St. Joseph	1.4	875
Walloon or Bear	Charlevoix-Emmet	7	*a* 685	Turtle	Montmorency	1.3	*a* 850
Douglass	Cheboygan	5.5	*a* 700	Odessa	Ionia	1.3	825
Crooked	Emmet	5	600	Orchard	Oakland	1.3	930
Intermediate	Antrim	5	607	Corey	St. Joseph	1.3	875
Portage	Manistee	4	580	Paw Paw	Berrien	1.3	630
Long	Grand Traverse	4	*e* 836	Sage	Ogemaw	1.25	*a* 850
Big Sable	Mason	4	582	Silver	Grand Traverse	1.25	875
Big Clam	Wexford	3.5	1,280	Au Sable	Oceana	1.25	580
Platte	Benzie	3.5	*a* 595	Fremont	Newaygo	1.25	780
Missaukee	Missaukee	3.5	*a* 1,240	Pierce	Emmet	1.25	620
St. Helens	Roscommon	3.5	1,150	Devil	Alpena	1.25	595
Tawas	Iosco	3	585	Reed	Kent	1.25	750
Portage	Crawford	3	1,130	Devil	Lenawee	1.25	1,050
Otsego	Otsego	3	1,270	Long	Genesee	1.2	*a* 900
Bear	Manistee	3	*a* 760	Crystal	Montcalm	1.1	*a* 800
White	Muskegon	3	580	Lakeville	Oakland	1.1	*a* 975
Grass	Antrim	3	595	Long	Kalamazoo	1.1	870
Carp	Emmet	3	715	Crooked	Missaukee	1	1,240
Gun	Barry	3	*a* 720	Thumb	Charlevoix	1	*a* 1,060
Gull	Kalamazoo	2.75	*a* 850	Bass	Mason	1	580
Van Etten	Iosco	2.5	589	White	Oakland	1	*a* 1,020
Duck	Grand Traverse	2.5	*e* 819	Whitmore	Washtenaw	1	894
Green	.....do	2.5	*e* 803	Portage	.....do	1	851
Round	Antrim	2.5	589	Pine	Barry	1	*a* 900
Black	Ottawa	2.5	580	Wamplers	Lenawee	1	*a* 1,000
Little Clam	Wexford	2	1,280				

a Determined by aneroid barometer.
b Alexander Winchell gives this altitude as 1,170 feet.
c Spirit levels run by Prof. J. B. Davis, of the University of Michigan.
d Determined by Prof. A. W. Grabau, of Columbia University.
e Spirit levels run by J. J. Hubbell, chief engineer of the Manistee & Northeastern Railroad.

STREAMS.

PREGLACIAL DRAINAGE.

Concerning the course of preglacial drainage very little can be determined in a region with such great drift accumulations.

In Indiana borings from the vicinity of Lafayette westward have disclosed a preglacial valley, with a rock floor scarcely 300 feet above sea level, running westward a little north of Wabash River. The borings indicate that a deep valley leads into this from the north and

another from the east, both joining it not far from the city of Lafayette. The one from the north probably carried the drainage of a considerable part of northern Indiana, and possibly was the line of discharge for the southern portion of the basin now covered by Lake Michigan.

A preglacial valley, which has been traced from Celina, Ohio, westward into northern Indiana and which passes near Geneva, Hartford, Marion, and Peru, probably belongs to the same system as that draining northern Indiana; in this valley the drift is nearly 400 feet thick, whereas on the interfluvial tracts on either side it is less than 100 feet thick. The presence of such valleys must be taken into account in estimating the thickness of drift.

In the southern peninsula of Michigan one of the most important preglacial valleys leads from the head of Saginaw Bay southwestward into Gratiot County and thence westward and northwestward to the Lake Michigan basin north of Ludington. (See Pl. IV.) It indicates a drainage from the Saginaw basin to the basin of Lake Michigan, as the floor becomes lower in passing westward from Saginaw Bay.

PRESENT-DAY DRAINAGE SYSTEMS.

The greater part of Indiana is tributary to the Wabash, itself a tributary to the Ohio; the southern end of the State is directly tributary to the Ohio through smaller streams; the northeastern part drains through the Maumee to Lake Erie and the northwestern part largely through the Kankakee to the Illinois, though a narrow strip drains to Lake Michigan. The southern peninsula of Michigan drains entirely to the Great Lakes, the western half to Lake Michigan, and the eastern half chiefly to Lake Huron and its arm, Saginaw Bay, though some small areas in the southeastern part drain to Lakes St. Clair and Erie and to St. Clair and Detroit rivers.

The boundaries between the several river systems fall mainly within the glaciated region and are largely determined by glacial accumulations. The only important water partings within the glaciated portion of Indiana which to any marked degree coincide with the elevated rock surfaces are in southern Randolph County between the headwaters of White River, a tributary of the Wabash, and those of Whitewater River, a direct tributary of the Ohio; but even here the water partings result only in a general way from the elevated rock surface, their precise position being determined by morainic accumulations. The water parting between the tributaries of the Wabash and the small tributaries of the Ohio in southern Indiana from the meridian of Salem westward is chiefly due to rock irregularities, for most of the small Ohio tributaries lie wholly in unglaciated territory; but from near Salem eastward the water parting is inside the glacial boundary and is only in a general way dependent on the rock surface.

In the southern half of Michigan the high altitude of the rock surface determines in a general way the divide between the westward drainage to Lake Michigan and Saginaw River and the eastward drainage to Lake Huron, St. Clair River, Lake St. Clair, Detroit River, and Lake Erie. In the remainder of the southern peninsula the water partings show little or no dependence on the rock surface.

DEVELOPMENT OF PRESENT DRAINAGE.

Some of the present drainage did not come into existence directly on the withdrawal of the ice. During the occupancy of the immediate basins of Lakes Michigan, Huron, and Erie by the ice sheet the territory to the south was tributary to Mississippi River either through the Wabash and Ohio, the Kankakee and Illinois, or the Desplaines and Illinois. Lakes held between the ice and the present St. Lawrence-Mississippi divide discharged across the latter through large and well-defined outlets, that to the Wabash being known as the Fort Wayne or the Erie-Wabash outlet and that to the Desplaines as the Chicago outlet. Glacial lakes discharged also through outlets leading across the southern peninsula of Michigan, conspicuous among which were the Imlay, the Ubly, and the Grand River outlet.

Little of the present drainage within the glaciated portion of this region coincides for any great distance with the preglacial lines. Many of the streams are too shallow to reach the

bottom of the glacial deposits, and those that have cut through them commonly encounter merely the crests of preglacial rock ridges; throughout the greater part of both Indiana and Michigan the beds of the present streams are above the tops of the rock ridges of the districts they traverse.

The drainage varies from a very immature stage, in which the streams have scarcely begun to open a channel, to a well-defined, widely branching system with well-graded channels. Drainage within the glaciated region, however, is nowhere mature; in the Illinoian drift area much poorly drained surface remains even where channels are well graded; and in the Wisconsin drift area many of the stream channels themselves are immature and have numerous lakes along their courses.

In much of Michigan the development of surface drainage is proceeding very slowly, because the drift is sufficiently porous to rapidly absorb nearly all the rainfall. Many townships are wholly destitute of surface streams and are yet so well underdrained that the soil is not swampy. On the other hand, many tracts with clayey or impervious soil have plentiful surface drainage and yet remain swampy in parts because their soil absorbs so small a percentage of the rainfall.

THICKNESS OF THE DRIFT.

The region covered by this monograph probably embraces the largest area of thick drift in North America. The greater part of the southern peninsula of Michigan and the northern and central portions of Indiana are so deeply covered that wells seldom reach the rock. The average thickness of drift in the southern peninsula of Michigan, as determined by Cooper's planimeter measurements, already noted, is about 300 feet, and an equally great thickness prevails over several counties in northern Indiana. It is probable that on parts of the southern peninsula of Michigan nearly 1,000 feet of drift is present. In Indiana the greatest thickness reported is about 500 feet (at Kendallville).

The geologic map of the southern peninsula of Michigan (Pl. II) shows the rock altitude by bedrock contours. On part of the western side of the State, from Ludington northward about to Frankfort, the rock surface lies about at sea level and to reach it wells near the level of Lake Michigan penetrate over 600 feet of drift.

In Indiana the distribution of the belts of thick drift (Pl. IV) is in part due to the filling of preglacial valleys, notably the Whitewater, the East White, and the Wabash. In the central and northern parts of the State, however, the drift is 100 feet or more thick on the preglacial interfluvial tracts and 300 to 500 feet along the lines of preglacial drainage.

CHAPTER III.

PRE-WISCONSIN DRIFT AND ASSOCIATED DEPOSITS.

By Frank Leverett.

LIMIT OF GLACIATION.

The mapping of the glacial boundary or drift limit in Indiana and Kentucky (see Pls. V and VI) has been brought to its present state through the work of various individuals. In several of the early reports of the Indiana Geological Survey notes on the drift limit are given in connection with more detailed descriptions of the subjacent rock formations. Somewhat later G. F. Wright[1] extended his observations on the limit of glaciation westward from Ohio into Illinois with results sufficiently full to warrant a map setting forth the approximate limit, though he did not, as appears from later studies, give the exact boundary in all districts. The present writer subsequently reconnoitered the border of the drift both in Kentucky and Indiana and presented the results in Monographs XXXVIII and XLI of this Survey. This reconnaissance, it is believed, fixed the limit of glaciation within 1 to 5 miles of its precise position. Owing to the attenuated and patchy condition of the drift near the border he found more precise work difficult. Subsequent to the publication of his reports, Fuller[2] and Clapp[3] made a more detailed study of the glacial boundary in southwestern Indiana, determining its character between East White and Wabash rivers more accurately than has been done in any other part of Indiana.

The border of the well-defined drift deposits enters Indiana from Illinois near the mouth of Wabash River and follows Big Creek and its north or main branch northeastward into northwestern Vanderburg County, whence it runs slightly north of east, entering Gibson County south of Haubstadt. It then runs northward to near Francisco and then eastward past Oakland into Pike County, but within a short distance beyond turns northward and crosses Patoka River and the divide between Patoka and White rivers near the meridian of Petersburg. Here its position is obscured by the deposits of a small glacial lake, Lake Patoka, which covered a considerable area in northeastern Pike and northwestern Dubois counties. The lake extended as far southeast as Jasper, but the ice apparently ended just south of East White River.

Beyond the area of Lake Patoka the border of the glacial drift crosses to the north side of East White River near Portersville and takes a course slightly east of north to Loogootee, keeping a short distance west of East White River. It then trends northward near the line of Daviess and Martin counties past Burnes and Scotland and into Greene County to Newark, whence, as determined by Siebenthal for the Indiana Survey, it goes northeastward across southeastern Owen and northwestern Monroe counties to the edge of Morgan County.

Here the glacial boundary is at its northernmost point in Indiana. Its course thence southeastward to Ohio River has been less accurately traced. It turns somewhat abruptly southeastward across the northeast corner of Monroe County to Needmore in Brown County and passes north of Marshall to Mount Liberty in eastern Brown County. Thence it runs southward near Brownstown, Mount Sidney, Little York, Vienna, and Henryville to the Ohio opposite Louisville. It seems to follow the Ohio, without crossing into Kentucky, for several miles above Louisville, and it does not leave the Ohio Valley to strike back into Kentucky until it reaches Bedford, Ky. East of Bedford it remains on the Kentucky side of the Ohio for about 60 miles, or until far past the eastern border of Indiana. It crosses the Ohio into the State of Ohio about 25 miles above Cincinnati.

[1] The glacial boundary in western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois: Bull. U. S. Geol. Survey No. 58, 1890.
[2] Fuller, M. L., and Ashley, G. H., Ditney folio (No. 84), Geol. Atlas U. S., U. S. Geol. Survey, 1902.
[3] Fuller, M. L., and Clapp, F. G., Patoka folio (No. 105), Geol. Atlas U. S., U. S. Geol. Survey, 1904.

DIAGRAMMATIC REPRESENTATION OF THE OUTLINE OF THE ICE BORDER AT SEVERAL SUCCESSIVE POSITIONS AND THE DIRECTION OF ICE MOVEMENT IN CONNECTION WITH EACH POSITION.

Fuller[1] and Clapp[2] have found that stratified drift in local patches occurs for several miles south of the limit given in Monograph XXXVIII and that a few drift pebbles occur still farther south. The distribution of these patches of stratified drift is not readily accounted for by the ordinary processes of stream deposition nor by the existence of ponded waters during their deposition. The evidence of an extension of the ice over this region of patchy stratified drift is far from conclusive and the explanation of these features must await further investigation. Cox,[3] many years ago, reported the presence of a granite bowlder on a hillside above the village of Carrsville in Livingston County, Ky., still farther outside the limits of well-defined glacial deposits than the gravels noted by Fuller and Clapp.

ILLINOIAN AND PRE-ILLINOIAN (?) DEPOSITS.

COMPLEXITY OF THE BOUNDARY.

The boundary just delimited is apparently that of the Illinoian stage of glaciation. In its vicinity in Indiana and at some points some distance back from it certain features are apparent which suggest some complexity of glacial movement and deposition. Whether they are the product of an oscillating ice front in a single stage of glaciation or represent two distinct stages of glaciation remains to be determined.

Early reports of the Indiana Geological Survey contain a few scattered records of the existence of a black mucky soil interbedded with the marginal drift. As the soils reported are near the glacial boundary, where the upper sheet is practically coterminous with the lower one, they may be interpreted as having been formed during a slight recession of the ice and covered by a fresh advance. Other features, however, suggest greater complexity. Nuggets of copper and certain associated rocks of the Lake Superior region are present in the drift deposits of central Indiana nearly to the glacial boundary and farther east in western and central Ohio, and suggest an ice movement from the Lake Superior region. They apparently occur in the basal portion of the drift, and thus may underlie the drift from the Labrador field.

BURIED SOIL.

A special effort was made in the summer of 1903 to determine the character of the interval represented by the buried soil of the marginal portion of the drift, but the definite results hoped for were not fully obtained. Examinations of exposures in the hilly counties in central Indiana developed the fact that flat tracts inclosed among the hills are the best localities for the preservation of the buried soil. Of these tracts the most extensive and, on the whole, the most satisfactory is an area of 50 to 60 square miles in southern Putnam and northern Owen counties, known as the "flatwoods." It is underlain largely by Mississippian limestone, which has a nearly level surface preserved apparently in tabular form. This condition of the underlying rock has much to do with the flatness of the surface. The following beds are exposed in the numerous ravines and road gradings:

Representative section exposed in ravines in southern Putnam County.

	Feet.
Surface silt or clay, white, pebbleless; apparently a correlative of the main loess deposit of the Mississippi basin	4- 6
Soil, black, gummy, or gumbo, with quartz pebbles, representing apparently the Sangamon interglacial soil	1- 3
Till, brown, generally with deeply weathered surface, apparently of Illinoian age	3-15
Gumbo, black, changing to blue or gray below; generally containing a few pebbles	1- 8
Till, brown, extending to bottom of ravines, in places changing to blue; exposed	5-10

Twenty feet or more of the black mucky material is reported beneath the upper sheet of till in certain wells in the region, but no exposure exceeding 8 feet was found in ravines. In one exposure the till immediately below the lower soil is blue, and in nearly all it is only slightly oxidized; indeed, in only one was it found to be highly weathered. This exposure, which is in

[1] Fuller, M. L., and Ashley, G. H., op. cit.
[2] Fuller, M. L., and Clapp, F. G., op. cit.
[3] Tenth Ann. Rept. Geol. Survey Indiana, 1878, p. 106.

a ravine crossing from T. 13 N. into T. 12 N., R. 3 W., about 2 miles east of Cloverdale, near the corner of secs. 33, 34, 3, and 4, shows a buried mucky soil 6 to 8 feet thick, underlain by till that is redder and apparently more weathered than the till above. The buried muck beds are perhaps as conspicuous in these flat areas among the hills of central Indiana as are those found between the Illinoian and Kansan drift sheets of southeastern Iowa, but they are not underlain by the highly weathered and oxidized till sheet that characterizes the upper part of the Kansan drift in Iowa. The results of the study, therefore, leave the occurrence of a long interval of deglaciation in doubt.

MINERALS IN THE DRIFT.

COPPER.

In the absence of other and conclusive evidence of direct invasion the nuggets of native copper in the basal portion of the drift should not be given great weight. It is possible that the copper was transported into districts farther north by ice movement across the Superior region from the Patrician field and was then brought into this region by the Labrador ice sheet from points where it chanced to cross the deposits of the earlier ice sheet. This area in south-central Indiana is in a reentrant angle between the Illinois lobe and the lobe covering eastern Indiana and western Ohio and is likely to have received contributions from both. The path of the Illinois lobe is such as to bring deposits from far north if not from the outcrops of copper-bearing rocks in the eastern end of the Superior basin. So far as this particular area is concerned, therefore, the sufficiency of the evidence of an invasion from the Superior region is doubtful.

GOLD.

With the nuggets of copper have been found small amounts of gold, and also a few diamonds and chunks of lead. The copper, diamonds, and lead seem to have been derived from the base of the drift; the gold, however, comes from considerable heights above the base as well as low down, as has been proved by the observations made by R. L. Royse, of Martinsville, Ind., during the sinking of a shaft 5 miles northwest of Martinsville in sec. 24, T. 12 N., R. 1 W., on the slope of a large gravel hill which presumably was formed as a closing feature of the ice occupancy of this region. The shaft was started 65 feet below the highest point of the hill and was sunk to a depth of 135 feet without entering rock. The material was panned for its entire depth and yielded gold at all levels from top to bottom. The following record of the shaft was obtained from Mr. Royse:

Section of Royse gold shaft, 5 miles northwest of Martinsville, Ind.

	Feet.
1. Gravel and cobble, coarse, with a few bowlders, extending to level of base of gravel hill, waterbearing near bottom	32
2. Reddish clayey cemented crust with much iron	3
3. Clay, blue, gummy	6
4. Sand, coarse, and fine gravel, nearly dry	30
5. Sand, fine, with but little water	40
6. Gravel, reddish, with light streaks	14
7. Clay, deep blue	10
	135

The "colors" or flakes of gold were most abundant in 1 and 4. The fine sand (5) contained only minute "points" of gold, but the reddish gravel which underlies it showed flakes as coarse as those in 1 and 4.

DIAMONDS.

Drift diamonds have been found southeastward from the neighborhood of Minneapolis Minn., across Wisconsin, Michigan, and Indiana into Ohio. Hobbs [1] discussed their distribution

[1] Hobbs, W. H., The diamond field of the Great Lakes: Jour. Geology, vol. 7, 1899, pp. 375-388.

in the light of glacial movements and concluded that they may have all been transported by the Labrador ice field from the vicinity of the south end of Hudson Bay or from the district between Hudson Bay and Lake Superior, from which there is clear evidence of movement toward the southwest and south to the localities where the diamonds have been found. But though the movements of the Labrador ice field at both the Wisconsin and the Illinoian invasions would favor such a derivation for the diamonds, or at least for those found between the Wisconsin driftless area and Cincinnati, it should be remembered that like the copper they may also have been transported by ice from the Lake Superior region, if that ice extended southeastward through the upper Great Lakes basins into Indiana and Ohio prior to the extension of the Labrador ice field into the same region. Such a movement may have brought them from the Patrician ice field recently described by Tyrrell.[1] (See p. 24.) It is necessarily difficult to work out the movements of such an ice sheet in territory where its deposits were subsequently overridden and concealed by the drift of the Labrador ice, yet such an earlier movement may contain the key to the home of the diamonds. If the lower of the two old drift sheets of Indiana and Illinois pertains to the movement from the Superior region and only the upper one to the Labrador field, the great extent of the diamond-bearing drift from northwest to southeast may indicate the course of transportation of the diamonds instead of the terminal line to which they were transported, and their home may be north of Lake Superior rather than northeast of it.

TOPOGRAPHY.

The contrasts in topography displayed by the pre-Wisconsin drift are fully as great as those displayed by the Wisconsin drift. Indeed, the pre-Wisconsin includes some of the sharpest drift ridges of the State and some of the smoothest plains. The ridges and knolls of this older drift are less systematically distributed and are less definitely confined to moraines or otherwise connected with the ice border than those in the newer drift. However, as far north as southern Michigan, pre-Wisconsin ridges of morainic type are distributed in belts concentric with the great basins.

The flat surface of the greater part of the pre-Wisconsin drift, not only in Indiana but also in Ohio and Illinois, seems to indicate that the retreating ice border did not make prolonged halts such as characterized the recession of the ice border in the Wisconsin stage. Even along its southern edge the knolls and ridges of the older drift can scarcely be said to form a moraine, for they are loosely distributed and level surfaces predominate. Scattered over the older drifts kames or sharp gravelly knolls rise either singly or in clusters to heights of 20 to 50 feet or more above bordering nearly plane tracts; many of them stand in low areas along the line of preglacial valleys or on valley slopes, and in such situations some of them reach heights of over 100 feet.

As already indicated, a few ridges of drift several miles in length have been developed. One such ridge, in Morgan County, along Indian Creek southeast of Martinsville, is scarcely one-half mile wide and is 50 to 100 feet or more in height. Another, within the limits of the later or Wisconsin drift, in southwestern Shelby County, is known as Mount Auburn Ridge, the village of Mount Auburn being on its crest; it is about 9 miles in length, 2 miles in width, and 75 to 150 feet in height, with an irregular surface on which knolls rise abruptly 50 to 75 feet. The mantle of later or Wisconsin drift is remarkably thin, the thickest deposit noted being only 15 feet in depth. A third conspicuous ridge is Chestnut Ridge in Jackson County, first described by Cox[2] and also discussed at some length by the present writer in Monograph XLI; its length is about 8 miles, its width but little more than one-half mile, its height 50 to 170 feet, and its surface somewhat hummocky and irregular. Wells on the ridge show part of it to carry a coating of till 50 feet or more in depth, but the greater part seems to be gravel and sand.

[1] Tyrrell, J. B., Hudson Bay exploring expedition, 1912: Twenty-second Ann. Rept. Ontario Bur. Mines, pt. 1, 1913.
[2] Sixth Ann. Rept. Geol. Survey Indiana, 1874, pp. 42, 56–57.

All these ridges appear to be made up mainly of waterworn assorted material and should perhaps be classed as kame moraines, though they are not parallel with the neighboring parts of the glacial boundary. The Mount Auburn Ridge trends north-northeast and south-southwest, directly toward the glacial boundary instead of parallel with it. The trend of the other two ridges diverge only slightly from that of the neighboring glacial boundary, and they are each within about 5 miles of the limits of the well-defined drift sheet. Mount Auburn Ridge appears to have been formed at the junction of converging ice currents, for it stands back of a sharp bend or reentrant in the glacial boundary.

Detailed mapping of the knolls of this earlier drift has not been attempted. In the hilly districts along the drift border it is difficult correctly to interpret some of the hills, for some which had been supposed to have a rock nucleus have been proved by boring to be made up very largely of drift. Even the detailed studies by Fuller and Clapp in the quadrangles in southwestern Indiana were not carried far enough to warrant a separation of all the drift hills from those with a rock nucleus.

Ridges of pre-Wisconsin drift some distance inside the limits of the Wisconsin, though known by borings to be present, are so deeply buried under the later drift that little is known concerning their topography. Those in southeastern Michigan appear to be broad, massive belts rather than sharp ridges. They will be considered in connection with the discussion of the later drift.

STRUCTURE OF THE PRE-WISCONSIN DRIFT.

COMPOSITION.

The glacial deposits found outside and also beneath the Wisconsin drift for some distance inside its limits consist very largely of a clayey till oxidized to a brownish color near the surface but becoming a blue-gray unoxidized till at a depth of 20 feet or less. The till as a rule is thickly set with small stones and contains some bowlders, though few large ones; often several exposures must be examined to find one that exceeds a foot in diameter. Yet some 4 to 6 feet in diameter have been found clear out to the limits of glaciation.

The character of this drift sheet varies to some extent in accord with the underlying rocks, yet in other respects it is constant. Thus the calcareousness of the till is striking even in districts where it overlies sandstone. The rock constituents include limestone derived from the formations along the path traversed by the ice. The character of the drift sheet varies with the drainage conditions along the ice border; thus gravelly and sandy material is scarce over much of the area of exposure in western and eastern Indiana but is more common in central Indiana. In Owen, Morgan, Johnson, and Brown counties, Ind., sand and gravel form the bulk of the drift knolls and ridges as well as the filling in the preglacial valleys. The attenuated border in Pike and Gibson counties, as indicated by Fuller and Ashley,[1] contains considerable sand and gravel, but the preglacial valleys of that region, except the Ohio and Wabash, are largely filled with silt or fine sand. Records obtained in several counties in southwestern Indiana show that the pebbly glacial material forms only a thin capping of the surface.

The silt filling is attributable to deposition in ponds caused by ice blocking the mouths of valleys that drained northwestward, and hence were favorably situated for receiving the turbid discharge from the ice sheet but not for receiving the coarser outwash. These silt deposits were eventually covered by the advancing ice as far out as the limits of glaciation. Their calcareousness in a sandstone region, such as that of most of the valleys thus filled, shows clearly that the ice sheet contributed the material. Wells in these silts yield decidedly harder water than those sunk in the rock formations of the region, and this condition of the water has furnished an index of the nature of the silts at many points where they have not been exposed to view.

Valleys with this sort of filling are conspicuous in Posey, Gibson, Vanderburg, Pike, Dubois, Davis, Clay, and Vigo counties and occur in other counties. In places the silts underlie

[1] Ditney folio (No. 84), Geol. Atlas U. S., U. S. Geol. Survey, 1902, p. 3.

glacial ridges, a conspicuous instance being a ridge that rises 30 to 50 feet above the railway station east of Fort Branch. This ridge is composed of loose-textured reddish drift carrying considerable sand and a moderate number of bowlders and coarse pebbles. The wells along it enter what is termed "blue mud" at about the level of the base of the ridge and continue in it for 40 to 60 feet until they reach rock.

South of the west-flowing parts of East White and White rivers in Dubois, Pike, Gibson, Posey, and Vanderburg counties there is very little typical till. The clayey parts of the drift carry few pebbles and exceedingly few bowlders. Both the clayey and the sandy deposits indicate that lake or water action was so combined with glacial action as to influence nearly all the glacial deposits. The uplands carry only scanty glacial material, a thickness of 10 feet being rare, but the valleys contain 75 to 100 or more feet, including the silt deposits above described.

The general presence of till in the district north and west of White River puts it in contrast with the district to the south and east, and the amount of drift on the uplands is much greater, reaching depths of 20 to 60 feet or more.

The deposits in some preglacial valleys are described as black mud, though their color is usually blue or gray. The most conspicuous occurrences are in the valleys of Eel River and White River in Clay and Greene counties, and are possibly flood-plain deposits antedating the glacial invasion, though the absence of samples makes it difficult to judge.

INTERBEDDED DEPOSITS.

BURIED SILT OR LOESS.

In scattered exposures in the southwestern counties of Indiana fossiliferous silt very similar to the loess that overlies the till occurs beneath or is interbedded with the till. It may, however, be of small extent and may not represent widespread conditions such as prevailed during the main loess deposition. Several occurrences were examined in 1902 by M. L. Fuller and the writer.

Loess was found interbedded with till about 5 miles south of Hazleton in eastern White River Township, Gibson County. The overlying till is of the ordinary clayey type characteristic of the Illinoian drift sheet and is thickly set with pebbles. The underlying deposit seems to have fewer pebbles but is apparently glacial. The loess is gray and contains many fossils. The exposures were not sufficient to determine whether both the drift sheets and the included loess belong in the Illinoian stage or whether the lower drift belongs in an earlier stage of glaciation. The lower sheet appears to be fully as much oxidized as the upper. The loess outcrops in a gully at the roadside and appears to be 12 to 15 feet thick.

Buried loess was also found on the north bluff of the Ohio about 16 miles below Rockport, Ind., in sec. 4, T. 8 S., R. 7 W., where it is separated from the surface loess by a bed of pebbly clayey alluvium. The following section was observed along the newly graded road leading down to the Ohio Valley from the residence of Mr. Deyss on the bluff:

Section of Ohio River bluff at Deyss private road, sec. 4, T. 8 S., R. 7 W.

	Feet.
Loess, brown, loose textured	11
Clay, brown, slightly pebbly, becoming gray near base	14
Loess, gray, very thickly set with fossils	15
Clay, sandy, of marbled brown color, containing pebbly layers	13
Gravel, bronzed, apparently redeposited from the preglacial gravels outcropping in the bluff farther up the Ohio	17
	70

Scarcely 100 yards east of this road the bluff showed material change, as appears in the following section:

Section of Ohio River bluff 100 yards east of Deyss private road.

	Feet.
Loess, brown, loose textured	15
Clay, white, close textured	6
Clay, sandy, with layers of pebbles, not bronzed	13
Gravel, coarse, not bronzed	3
Gravel, bronzed, in cemented bed	1
Gravel, bronzed, uncemented	31
	69

In passing from the exposure last given westward to the wagon road the upper part of the bronzed gravel gives place to the sandy marbled-brown clay with pebbly layers about as a rock formation gives place to a drift deposit where the drift appears in the lee of a rock cliff in glaciated districts. The fossiliferous loess of the first exposure is not represented in the second and appears, therefore, to be a local deposit. Veatch[1] has called attention to other sections in this vicinity somewhat different from either of these and as difficult to interpret.

BURIED SOIL.

The occurrence of two drift sheets separated by a black soil or humus-stained gummy clay is most common in Putnam and Owen counties. Indeed, the present writer was unable to learn of any instances of it in the southwestern counties, the black material in the latter region being usually beneath all the glacial deposits. The same is true in most places in southeastern Indiana. This soil in Putnam and Owen counties was discussed by Collett[2] in an early report, as follows:

> Wells to the number of 8 or 10 in the village [Quincy] at a depth of 15 to 30 feet pierce a black mucky soil containing brush, trees, leaves, grass, etc. This unctuous clay is characteristically lacustral. It is underlaid with quicksand and fine glacial gravel.
>
> One of the wells in the village gave the following exhibit:
>
> *Section in Quincy well.*
>
> | | Ft. | In. |
> |---|---|---|
> | Soil, black | 1 | 8 |
> | Clay, white and gray, with crawfish pipes, with little sand, no pebbles | 10 | 0 |
> | Clay, blue, with pebbles | 3 | 0 |
> | Clay, black, mucky, with brush and plant remains | 3 | 0 |
> | Hardpan and fine pebbles | 3 | 0 |
> | Gravel, coarse, and bowlders (depth unknown) | 3 | 0 |
> | | 23 | 8 |
>
> The trunks found in the above were of trees 4 to 5 inches in diameter, generally crushed or broken to pieces. The insertion of the branches was opposite or alternate like fir or ash and the rings of growth were compressed and fine, as if subject to a cold climate.

The present writer obtained records of wells near Quincy that passed through much more black mucky clay than is reported in the above section. In L. M. Combs's well, one-half mile east of the village, it extends from 14 to 28 feet below the surface; in G. W. Raikes's well, 2 miles west, it extends from 13 to 31 feet; and in O. W. Raikes's well, a short distance farther west, it extends from 8 to 40 feet. In each of these wells water-bearing gravel and sand underlie the black muck. Another well with a large amount of the black mucky clay was made by Samuel Beman 1½ miles northeast of Cataract, in the midst of the preglacial valley of Eel River. Its record, as interpreted by exposure in neighboring ravines, is as follows:

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[1] Jour. Geology, vol. 6, 1898, pp. 264–268.

[2] Collett, John, Seventh Ann. Rept. Geol. Survey Indiana, 1875, p. 319.

Record of Beman well near Cataract, Ind.

	Feet.
Clay, surface, including white clay and gumbo	14
Till, sandy and pebbly, of reddish brown color (Illinoian)	12
Clay, black, termed barnyard muck by owner	24
	50

The well mouth is about 150 feet above Eel River (below the falls) where the stream reenters its old valley; it is therefore probable that the drift extends 100 feet below the bottom of this well. Mr. Beman states that the muck became rather sandy and yielded water toward the bottom of the well but held its black color. The well has been in use many years and the water appears to be of good quality.

In the southeastern part of Owen County, occupying the highest land between Spencer and Ellettsville, is a level tract known as the Flatwoods, which has been examined and reported upon by C. E. Siebenthal.[1] It is 2½ miles wide and 6 miles long. The southeastern end apparently is at the limits of glaciation. It carries an alternation of clay and sand beds with buried wood, and is thought by Siebenthal to have been occupied by a small glacial lake. He gives the following well record as typical of the region:

Record of well in Flatwoods district in sec. 31, T. 10 N., R. 2 W.

	Feet.
Soil and clay	17–18
Embedded logs	1
Clay	8
Gravel, waterworn	1
Clay, blue, sticky	8
Limestone.	

Collett[2] gives the following section in the same region:

Record of well in Flatwoods district in SE. ¼ sec. 26, T. 10 N., R. 3 W.

	Feet.
Soil, black, mucky	8
Sand and fine gravel	6
Quicksand, blue, sticky, with logs, sticks, and leaves	8
Associated gravel and sand deposits.	

GRAVEL AND SAND DEPOSITS.

Heavy deposits of gravelly drift in the vicinity of Spencer rise 150 feet or more above the village and extend nearly 100 feet below its level. The gravel is in places cemented into a firm conglomerate that outcrops like a ledge in the hillside. The cross-bedding in an exposure one-half mile northeast of Spencer indicates a stream flowing southward. The gravel there fills a preglacial valley leading into White River at Spencer from the north. Except in the vicinity of White River there are no conspicuous deposits of sand and gravel in Owen County, the drift back from the river being generally clayey.

Gravel and sand occur principally in Morgan, Johnson, Brown, and southwestern Shelby counties, as these counties stand immediately north of the great reentrant angle in the glacial boundary. It is probably because of this interlobate position that kames and gravelly deposits are more abundant here than in districts east or west. In eastern Morgan County gravel deposits abound from Indian Creek valley northward to White River. The gravel knolls or kames appear not only outside the border of the Wisconsin drift but for some distance inside it. Some of the latter apparently received only a thin coating of the later drift and were modified remarkably little by the readvance of ice. In western Morgan County gravel knolls or kames are present, but are far less numerous than in the eastern part, much of the drift being a clayey or sandy till. It is in one of the prominent kames in this part of the county that the gold shaft noted on page 64 was sunk. Flat-surfaced gravelly deposits of considerable

[1] Twenty-first Ann. Rept. Indiana Dept. Geology and Nat. Res., 1897, pp. 301–302.
[2] Seventh Ann. Rept. Indiana Geol. Survey, 1875, pp. 333–334.

extent occur in the valleys of this county and have been penetrated by wells to depths of about 100 feet before entering rock. These deposits along White River may be, in part, of Wisconsin age, but on some of the tributaries of the river they are known to be outside the limits of the Wisconsin sheet. In this connection it may be remarked that valleys in northern Monroe and Brown counties which are outside the limits of the Wisconsin outwash carry deposits of gravel and sand, which, in the several forks of Salt and Bean Blossom creeks, form terraces lying 30 feet or more above the streams. In these valleys, as in the gulches of central and southern Morgan County, gold and a few diamonds have been found.

The gravel knolls of Johnson County, like those of eastern Morgan County, are in part within the limits of the Wisconsin drift and may be of pre-Wisconsin age, for the drift in them has a more weathered appearance than that of the surrounding deposits of Wisconsin age.

The Mount Auburn Ridge in southwestern Shelby County, as already indicated, is very largely of pre-Wisconsin drift. It has been penetrated by a few deep borings which show that the rock surface is considerably below its base. A well at the Mount Auburn schoolhouse, 198 feet deep, did not strike rock, passing largely through gravel, parts of which are cemented into conglomerate. Glacial conglomerate outcrops on the slopes of the ridge about a mile south of Mount Auburn. Collett reported that a well 1 mile west of Mount Auburn, on ground fully 100 feet lower than the village, struck rock at 108 feet. The following beds were penetrated:[1]

Record of well on Collins farm, 1 mile west of Mount Auburn, Ind.

	Feet.
Soil	4
Clay, yellow	6
Clay, sandy	10
Clay, bowlder	80
Sand, white	1
Sand and gravel	7
Limestone.	
	108

In Bartholomew County only the western edge lies outside the Wisconsin drift. Most of the surface is rugged, being a continuation of that in Brown County, with only a scanty coating of drift. There is, however, a narrow strip of lowland west of the East White Valley in which the drift has considerable depth.

Exposures west of Columbus along small tributaries of East White River show 50 feet of yellow till above blue till. Fifty-five feet of yellow pebbly clay and 5 feet of blue waxy clay above Devonian shale was found in a well on the farm of H. C. Harris, 1 mile west of Taylorville, very near the border of the Wisconsin drift; the greater part of the drift is thought to belong to the earlier ice invasion.

In the northeast part of Seymour, Jackson County, a gas boring passed through a black muck, apparently an old flood plain of East White River, at a depth of 55 to 65 feet, and other borings in the vicinity found the black muck at similar depths. No typical till appears to be present, the entire series of beds being water deposited.

Pleistocene beds penetrated in gas well at Seymour, Ind.

	Feet.
Sand, coarse	12
Sand or silt, very fine, almost a clay	43
Muck, black	10
Sand, coarse, with large amount of water	5
Clay, blue	5
	75

[1] Collett, John, Eleventh Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1881, p. 68.

A well at Harvey Morris's, near the north end of Chestnut Ridge, reached a depth of 89 feet, of which the upper 20 feet was clay, with only a few pebbles, and the remainder fine sand, becoming pebbly near the bottom. A well near by at Jerry Anderson's, 95 feet in depth, penetrated 52 feet of clay, pebbleless at the top but becoming a stony till below, overlying 38 feet of gray sand, too fine to screen, which in turn overlies gravel in which the well terminates. At Mr. Wieneke's, near the highest point on the ridge and 140 feet above the bordering plain, a well 77 feet deep penetrated 33 feet of sandy loam and loose sand, underlain by 40 feet of reddish gravel and sand with clay admixture; the well terminates in coarse gravel. E. T. Cox made a well on the low part of the ridge, scarcely 50 feet above the bordering plain, which penetrated ordinary till, largely yellow, for 50 feet and then passed through 58 feet of sand, which became coarser and somewhat gravelly near the bottom. From these well data it appears that the ridge has a variable structure such as would be expected in a kame moraine.

Several counties in southeastern Indiana, namely, Franklin, Decatur, Jennings, Ripley, Dearborn, Ohio, Switzerland, Jefferson, Scott, and Clark, received, at the Illinoian stage of glaciation, a sheet of drift estimated to average less than 20 feet in thickness, though much thicker in valleys. The drift is composed mainly of clayey till and is covered to a depth of several feet by a white clay or compact loess. In some of the valleys tributary to Ohio River gravelly knolls appear and along the borders of the Ohio itself there is some gravelly drift of the earlier ice invasion.

In a few places black muck and driftwood, noted near the bottom of the glacial deposits, suggest, as do features in central and southwestern Indiana (p. 63), some oscillation of the ice border, if not two distinct ice advances. The present writer has not seen exposures of the buried soil or muck and underlying drift in southeastern Indiana and is hardly prepared to express an opinion as to the time relations. Buried soils are noted in several wells in reports of the Indiana Geological Survey.[1]

Gold has been found in notable amount in four of these southeastern counties. Haymond[2] reported its occurrence on Sein Creek and its tributaries and on Little Duck Creek in Franklin County. He also noted the discovery in that county of a mass of native copper weighing 6 pounds. Gold in the Laughery Valley near Hartford, in Ohio and Dearborn counties, was reported by Warder[3] and has been panned with profit for many years. A nugget of copper that weighed 26 pounds was found in Dearborn County near Weisburg. Borden[4] reports that gold has been panned on the south fork of Muscatatuck Creek in Jennings County and is widely distributed in that region.

DRAINAGE.

The drainage conditions attending the Illinoian ice invasion have not been clearly worked out. As noted above there was an aggradation of valleys in southwestern Indiana during or before the Illinoian stage of glaciation that involved the tributaries of the Ohio and Wabash as well as the main valleys. In the tributaries only fine sandy and clayey material is reported; in the main valleys gravelly material occurs, but does not seem to fill the entire width, for borings at and between Evansville and Mount Vernon penetrate clay and fine sand similar to that in the tributaries.

In the Ohio Valley, on the border of southeastern Indiana, terraces of gravel derived from the Wisconsin drift show vigorous drainage at that late stage in the glacial epoch but furnish no clear evidence of vigorous drainage and gravel distribution down the valley during the Illinoian stage. In certain places along the valley at levels above the terraces of Wisconsin drift accumulations of gravelly materials were noted, but more commonly the valley was found to be filled with unassorted or very imperfectly assorted drift. The gravelly portions of this earlier drift are in many places cemented into a conglomerate, not only along the Ohio but also in the tributary valleys. The conglomerate at Split Rock, near Aurora, Ind., has long been

[1] Third Ann. Rept. Indiana Geol. Survey, 1872, pp. 262, 344; Seventh Rept., 1875, p. 172.
[2] Haymond, Rufus, First Ann. Rept. Indiana Geol. Survey, 1869, p. 190.
[3] Warder, R. B., Third Ann. Rept. Indiana Geol. Survey, 1872, p. 420. Also Tenth Ann. Rep., 1878, pp. 106-107.
[4] Borden, W. W., Seventh Ann. Rept. Indiana Geol. Survey, 1875, p. 178.

known, and several other outcrops of conglomerate are discussed in the reports of the Indiana Survey. The writer's examination of the conglomerate at Split Rock led him to the conclusion that it was formed from a very stony till rather than from an ordinary gravel and cobble deposit. The matrix is largely calcareous clayey material instead of sand and this is what binds the stones together so firmly. The stones include bowlders measuring 2 feet or more.

PRE-WISCONSIN DEPOSITS BENEATH WISCONSIN DRIFT.

The pre-Wisconsin drift found some distance inside the limits of the Wisconsin is best distinguished from the Wisconsin if it consists of a clayey till. Generally this till is much more indurated than that of the overlying Wisconsin drift and is thus recognized by the drillers. In places, however, the induration is less general and may even be localized in certain layers between which are layers of loose material; in such places it is not so easy to determine when the drill enters the gravel or sand of the pre-Wisconsin. Probably a considerable number of the heavy deposits of drift in central and northern Indiana are of pre-Wisconsin age, but as they are largely sand and gravel or loose-textured material they can not easily be discriminated from the Wisconsin. Buried soils found in several of the central counties and still farther north in parts of Lagrange County, Ind., and Hillsdale County, Mich., at depths of 25 to 100 feet, probably mark the line of separation.[1]

In the vicinity of Ann Arbor, Mich., a considerable number of wells, situated along a prominent moraine that traverses the Ann Arbor quadrangle in a northeast-southwest course, enter, at a general depth of about 100 feet, though in places much less, an indurated till, which is thought to be pre-Wisconsin. A similar till is found along the Huron River valley in the vicinity of Ypsilanti, Mich., and is reported in many wells in that vicinity. Indurated till is present also in the plain east of the Ann Arbor quadrangle and on the eastern slope of the "thumb" of Michigan as far north as Sanilac County, several exposures having been found along streams and along the shore of Lake Huron. (See Pls. XII and XIII.) The appearance of the till in this district is strikingly similar to that of the Illinoian drift outside the Wisconsin drift in Illinois and Indiana. Though generally blue-gray it is traversed by seams and vertical joints or cracks filled with a brownish or deeply oxidized material as in the typical Illinoian outside the Wisconsin. Along the Lake Huron shore it is so indurated that small streams cascade over it as they might over a rock ledge, and at Ypsilanti it has the appearance of a reef in the river bed in which potholes and other features commonly found in rock formations are present. Such induration is seldom if ever found in the clayey parts of the Wisconsin drift. This fact and the local occurrence of soil between the indurated drift and the overlying softer material make it reasonably certain that the deposits are pre-Wisconsin. The presence of such drift in this region is to be expected from the fact that the ice sheet which formed the Illinoian drift must have passed across the southern peninsula of Michigan to reach Indiana and Illinois. For details of the pre-Wisconsin deposits of central and northern Indiana and southern Michigan see pages 63–67 289–290.

STRIÆ OUTSIDE OF THE WISCONSIN DRIFT.

Observations of striæ in Indiana outside the limits of the Wisconsin drift are confined to seven counties, Owen, Putnam, Parke, Clay, Vigo, Sullivan, and Greene, all in the southwestern part of the State. The striæ bear from southward to eastward and, though somewhat divergent in the neighboring exposures, they all seem to fall in naturally with the movements of the Illinois glacial lobe, on the southern border of whose territory they appear. The following list comprises all which have come under the writer's notice:

[1] For an account of buried soils at Lagrange and Valentine, Ind., see Water-Supply Paper U. S. Geol. Survey No. 21, 1899, p. 26.

Striæ outside of the Wisconsin drift in Indiana.

Location.	Bearing.	Observer.
PUTNAM COUNTY.		
Sec. 25, T. 13 N., R. 4 W	S. 4° E	Leverett.
Sec. 22, T. 13 N., R. 4 W	S. 5° E	Do.
Sec. 28, T. 13 N., R. 4 W	N.-S	Collett.
Near Cloverdale	S. 3° 40′ E.[a]	O. P. Jenkins.
OWEN COUNTY.		
Near Romona	S. 18° E	Siebenthal.
Sec. 32, T. 11 N., R. 3 W	S. 22° E	Leverett.
3 miles south-southwest of Vandalia	W.-E	Wright.
5 miles west from the preceding	S. 40°-50° E	Do.
Sec. 20, T. 9 N., R. 5 W	S. 18°-46° E	Collett.
CLAY COUNTY.		
Sec. 6, T. 11 N., R. 5 W	S. 26° 30′ E	Collett.
3 miles south-southwest of Bowling Green	S. 32° 10′ E	Do.
Sec. 1, T. 11 N., R. 6 W	S. 36° 56′ E	Do.
Do	S. 34° E	Leverett.
Sec. 19, T. 11 N., R. 5 W	S. 26° 30′ E S. 30° 35′ E	Collett. Do.
VIGO COUNTY.		
Sec. 3, T. 10 N., R. 9 W	S. 20° W	Scovell.
Sec. 36, T. 10 N., R. 9 W	N.-S	Do.
SULLIVAN COUNTY.		
2 miles southeast of Farmersburg	N.-S	Do.
GREENE COUNTY.		
1 mile northeast of Worthington	S. 72° E	Leverett.
Sec. 6, T. 7 N., R. 4 W	S. 80° E	Siebenthal.

[a] Corrected S. 0° 35′ W. by Jenkins in 1888 for magnetic variation. Of the other observations Mr. Leverett's have not been corrected and the rest are not known to have been.

SANGAMON SOIL AND WEATHERED ZONE.

The Sangamon soil and weathered zone, formed on the surface of the Illinoian drift, has received attention in Monographs XXXVIII and XLI of this Survey, and little need be added concerning it. It separates the Illinoian drift by a very marked interval from the overlying loess and associated silt deposits. The writer has never observed the Illinoian drift to grade upward into the loess, either in Indiana or in the neighboring States, but has everywhere found it to be capped either with a deeply weathered zone or with a dark-colored soil.

These observations, however, are not in harmony with statements of several other geologists, who report gradations of the earlier or Illinoian drift into the overlying loess. The writer is of the opinion that these statements by his fellow workers are based on defective observations, for in two places occurrences claimed by two of his colleagues to illustrate such a transition were proved by a little excavating to afford good examples of an interval between the till and the loess, the surface of the till being deeply weather-stained. In these cases the talus had been taken to be material in place. Where loess has crept down a slope over an eroded till surface from which the weathered zone had been removed, the inference might readily be drawn that no marked interval had occurred.

The interval between the Illinoian drift and the loess is generally marked in Indiana by a dark-brown coloration and by disintegration or weathering of the upper part of the till sheet. The deep brown changes gradually below to the ordinary brownish-yellow color of oxidized till and then to the unoxidized blue or gray till, but at the top it terminates abruptly at the base of the much fresher looking overlying silt. The dark-brown color extends usually to a depth of only 1½ to 3 feet, but leaching and some discoloration by weathering is generally noticeable to a depth of 6 to 8 feet. Where the surface of the Illinoian drift was flat or poorly drained prior to the loess or silt deposition, a black gummy soil is found, which contrasts sharply in color with the overlying yellowish-brown loess or the pale white clay or silt. The black soil has been seen frequently in all parts of the Illinoian drift outside the Wisconsin or newer drift from central Ohio to southeastern Iowa and occasionally inside the limits of the newer drift. The dark-brown weathered till surface is to be seen in nearly every newly made exposure in the well-drained districts. As the general thickness of the overlying silt in

Indiana is but 5 to 10 feet on uplands and is even less on slopes, opportunities for observing the Sangamon weathered zone are very numerous.

POST-SANGAMON OR MAIN LOESS AND ASSOCIATED SILTS.

EXTENT AND DEPOSITION.

The weathered surface of the Illinoian drift and the outlying driftless territory in southern Indiana both bear a thin deposit of silt which is part of a practically continuous sheet that extends from Ohio westward beyond the Mississippi. In the vicinity of the main drainage lines it is loose textured and is commonly termed "loess." On the interfluvial tracts it ranges from a deposit readily pervious to water to one very slowly pervious. The least pervious portion is of a pale color and is termed "white clay."

The method of deposition of a large part of this silt is still in dispute and is one of the difficult problems of Pleistocene geology. Certain deposits of it along the main valleys, notably the marl-loess deposits of the Wabash, have been referred to fluvial action,[1] but generally along valleys as well as on interfluvial tracts the loess seems best explainable by wind action.

CHARACTER OF THE LOESS.

Analyses of the loess show that it is composed mainly of silica, the percentage of the material being from about 60 up to fully 80 per cent. Alumina, which is the next in order of abundance, except perhaps in very calcareous parts such as the marl loess of the Wabash, ordinarily constitutes 10 per cent or more. The amount of oxide of iron is notable, ranging from about 1 per cent to more than 6 per cent in the analyses at hand. The following analyses of loess and associated silts in Indiana have been taken from reports of the Indiana Geological Survey:

Analyses of the loess and white clay in Indiana.

	1	2	3	4
SiO_2	79.77	72.87	71.20	
Al_2O_3	9.95	11.25	18.56	60.00
Fe_2O_3	3.39	6.75	1.34	
FeO			.15	.80
TiO_2	.70	.95	.88	
MgO	.26	1.06	.52	
Na_2O	1.08	.39	1.26	1.00
K_2O	2.05	2.26	.32	
CaO	.67	.69	.14	20.27
CO_2				15.93
H_2O	2.55	4.24	6.30	2.00
	100.42	100.46	100.67	100.00

1 and 2. White clay near Terre Haute at depths of 10 and 22 inches, respectively. Analyst, W. A. Noyes.
3. Near Princeton. Analyst, Robert Lyons.
4. Near New Harmony. Represents the marl loess. Taken from Owen's report for 1838.

A number of samples of loess and more compact silt collected by the writer in western and southern Illinois and mechanically analyzed under the direction of Milton Whitney, of the United States Department of Agriculture, show that the pervious loess contains a smaller percentage of very fine particles than the compact, but that it contains no more coarse particles. Considerable variation is shown, but the bulk of the deposit, in some samples as high as 75 per cent, consists of grains which fall between 0.05 and 0.01 millimeter, or 0.002 and 0.0004 inch in diameter. Few grains measure more than 0.1 millimeter, or 0.004 inch. Some soils in the loess contain a larger percentage of grains below 0.01 millimeter than subsoils, a feature which probably results in part from the greater disintegration of soil particles and in part from the constant addition of very minute particles to the soil from dust carried in the atmosphere.

The thickness of the deposit in Indiana in few places exceeds 40 feet and is greatest along the Ohio and Wabash valleys. Within a short distance back from the bluffs of these valleys

[1] Bull. Geol. Soc. America, vol. 14, 1903, pp. 153-176.

it decreases to 10 or 12 feet and over the greater part of the region is between 5 and 10 feet. On slopes it is very thin, or wanting, because of erosion.

It should be borne in mind that the loess here discussed is not the only deposit of its class in the Pleistocene series. In not a few places, some of which are in southwestern Indiana (see p. 67), loess occurs beneath or interbedded with the Illinoian drift. Loess is also found to a limited extent on the outer part of the Wisconsin drift in central and eastern Illinois and western Indiana. The loess just discussed is thicker as well as more continuous and widespread than are similar deposits at other geologic horizons.

PEORIAN OR POSTLOESSIAL SOIL AND WEATHERED ZONE.

In Indiana there are but few places where the loess or its associated silts have been found under the Wisconsin drift, and in these the weathered portion of the loess seems generally to have been incorporated in the Wisconsin drift, leaving only the lower part for inspection. Exposures near Greensburg were noted by Chamberlin[1] in his early explorations in that region, and the writer found others in that vicinity. Concerning these exposures Chamberlin writes:

> At Greensburg and several points in the vicinity the interesting phenomena of the superposition of the newer upon the older drift is well shown. The best exhibit is in the southeastern part of the city, where the superficial deposits consist of about 7 feet of gray stony clay of fresh aspect, having suffered but a limited amount of superficial oxidation, and containing pebbles with polished and scratched surfaces, unleached and unweathered. This stratum is sharply terminated below and lies upon drift contrasted with it in high oxidation colors and the weathered character of the constituents. Examining more closely, the upper 2 or 3 feet of this lower stratum is found to be a loamy clay, partially stratified, and containing numerous molluscan remains. This is manifestly the superficial deposit of an old drift surface.

The writer found what seems to be a good example of the preservation of the entire white clay and its Peorian soil in an exposure in Coal Creek bluff in western Johnson County several miles inside the Wisconsin border, as indicated by the following section:

Section in bluff of Coal Creek near corners of secs. 29, 30, 31, and 32, T. 12, R. 3 E.

	Feet.
Till (Wisconsin), yellow at top but shading into blue-gray at bottom	20
Soil, black (Peorian)	1
Silt or clay, pale, greenish yellow, pebbleless (post-Sangamon)	3
Till (Illinoian), weathered and leached brown. Exposed	5
	29

The strongest evidence of an interval between the deposition of the loess and of the Wisconsin drift is perhaps found in a comparison of the amounts by which the two have been eroded. Although the erosion of the loess and associated silts is not strikingly greater than that of the outer portion of the Wisconsin drift, the difference is perceptible and indicates an interval greater than that between successive morainic systems of the Wisconsin drift. The time, however, between the loess deposition and the culmination of the Wisconsin glaciation, as marked by erosion and the forming of soil, seems to have been briefer than that between the Illinoian glaciation and the loess deposition.

SAND DEPOSITS ON THE LOESS.

The sand deposits which appear on the surface of the loess in southern Indiana are found mainly along the east sides of streams and have apparently been carried to their present position by wind. They commonly occur as short winding ridges scattered over a belt from 1 or 2 up to several miles in width on the borders of the main valleys. They are very conspicuous east of the Wabash Valley in northern and also in southern Vigo County and are a notable feature south from there through Sullivan, Knox, Gibson, and Posey counties. Sand deposits are conspicuous along the east side of White River in Gibson and Pike counties but are more sparingly distributed east of the south-flowing portion of the river in Daviess and Greene counties and are rather scarce farther north. Notable deposits lie east of the great bend of Eel River in

[1] Third Ann. Rept. U. S. Geol. Survey, 1883, p. 333.

southern Clay County. In southeastern Indiana the only notable accumulations are on the east side of East White River, in Jackson County.

In some of the valleys sand flats are still exposed to wind action and mild drifting is still going on. In other valleys the bottoms are coated with a mucky clay and no sand is within reach of the wind. This muck is a marked feature in the great bend of Eel River and occurs to some extent along White River below the mouth of Eel River. The change from sandy to mucky bottoms may find its explanation in a change from glacial to modern conditions. At the culmination of the latest stage of glaciation Eel River received drainage from the ice sheet and no doubt carried sandy material down its valley. But later this connection was cut off; vegetation and soils came in, and now the river carries only mud, with which it has built up or aggraded the valley bottoms several feet. The sand deposits, on this interpretation, consist largely of the Wisconsin outwash that the wind has carried up over the bordering loess-covered tracts.

CHAPTER IV.

THE WISCONSIN DRIFT BORDER.

By Frank Leverett.

CORRELATION OF THE BORDER MORAINES.

The Shelbyville or border morainic system of the Wisconsin drift of the Lake Michigan lobe in Illinois has been described in Monograph XXXVIII as far east as Greencastle, Ind. The Hartwell and Cuba, the outermost moraines of the Wisconsin drift of the Miami and Scioto lobes, respectively, in southwestern Ohio, have been discussed in Monograph XLI as far west as Connersville, Ind. There remains only an interval of about 100 miles, between Greencastle and Connersville, to be taken up in the present report.

Part of this distance, extending from Connersville west to East White River, is occupied by the moraine of the East White lobe, and the remainder is filled in by a less marked belt which connects near Greencastle with the Shelbyville morainic system. It was noted in the earlier volumes that some uncertainty was felt as to the correlation or equivalence of the outer moraines of Wisconsin drift in the Scioto and Miami lobes of Ohio, with the outer or Shelbyville morainic system of the Illinois lobe, for the reason that throughout much of the interval between Greencastle and Connersville the border of the Wisconsin drift is not marked by a definite ridge. The local names, Hartwell and Cuba, were therefore applied to the outer moraines of the Miami and Scioto lobes, respectively, though there is a strong probability that they are of the same age as the Shelbyville morainic system of the Illinois lobe.

COURSE AND DISTRIBUTION.

From Connersville, Ind., which stands in a reentrant angle between the Miami lobe and the East White lobe, the border of the Wisconsin drift leads southwestward to East White River at Elizabethtown, a few miles below Columbus, Ind. In the East White Valley the lobation is slight compared with that of the Miami and Scioto lobes, for on the west it protrudes only 10 to 12 miles. The border follows somewhat closely the east side of East White River in a course slightly west of north, to Taylorsville, 8 miles above Columbus, where it turns westward and crosses the north edge of Bartholomew County and the south edge of Johnson County into southeastern Morgan County. Thence it bears north of west across Morgan and Putnam counties to the vicinity of Greencastle, beyond which it runs westward to the Wabash Valley in Parke County, and then south and west across northwestern Vigo County into Illinois.

TOPOGRAPHY.

CONTRAST WITH ADJACENT COUNTRY.

MORAINE OF THE EAST WHITE LOBE.

In southwestern Fayette County, where the edge of the moraine of the East White lobe connects with the Hartwell moraine of the Miami lobe, its relief is only 10 to 20 feet above the silt-covered outer border tract. In northeastern Decatur County, however, for a mile or two in the vicinity of Kingston, it rises 30 feet or more above the outer plain. From Kingston southwestward to Elizabethtown, on upland tracts, a sharp rise of 10 to 20 feet from the outer border district is common. This relief, though slight, makes the border readily discernible.

The margin of the Wisconsin drift is easily traced through Decatur and Jennings counties by the soil as well as by the topography. The drift area is termed by the residents "black land," whereas the silt-covered outer border district is termed "white clay," "crawfish land," or "slash land." For more than 40 miles in Fayette, Decatur, and Jennings counties the border is so sharp and distinct that it can be located within a few yards. This abrupt change was early pointed out by Elrod, who recognized in a measure its relation to or dependence on glacial events.[1] The line of separation is very regular, passing without deviation over hills and valleys, showing but a rough adaptation to the contours, and giving positive evidence of glacial as opposed to glacio-natant drift deposition.

MORAINAL TRACT WEST OF EAST WHITE RIVER.

West of the East White Valley the Wisconsin border is less striking topographically. Instead of a ridge with continuous relief it presents only low swells and short ridges, few of which are more than 10 feet in height, and in many places they are scattered and inconspicuous. The contrast in soil is also less striking as a rule than it is east of the East White River, for the margin of the Wisconsin drift sheet is so thin and in places has so much silt or white clay incorporated with it that such occurrences can be identified only by close examination. In places the presence of pebbles alone serves to distinguish it from the white clay or surface silt of the outer border district. The admixture of silt, however, is conspicuous for only a mile or two back from the Wisconsin border, the till farther back being of a normal fresh type. And even in places where a large amount of the white clay has been incorporated with the Wisconsin till sufficient calcareous material is present to produce a richer soil than that of the white clay district. In addition to the contrast in soil the Wisconsin drift border is marked by surface bowlders of all sizes up to several feet in diameter. Outside the Wisconsin border the white clay has buried the bowlders of the Illinoian till sheet to a depth of several feet.

The course of East White River from Taylorsville to Columbus, a distance of 8 miles, was determined apparently by the Wisconsin ice invasion, for the stream is now flowing in a narrow valley just outside the Wisconsin drift border and not in the broad old valley once occupied by a preglacial and presumably by an interglacial predecessor that lies a short distance inside the border. The present stream cuts across the lower ends of tributaries of old streams, which are traceable eastward to the broad valley by sags or depressions.

ALTITUDE.

The altitude of the Wisconsin drift border within the State of Indiana has a range of more than 500 feet. In the vicinity of the reentrant angle between the Miami and East White lobes an altitude of fully 1,150 feet is found. From the high points in western Fayette County southwestward to McCoy station in Decatur County the general altitude of the border is between 1,000 and 1,100 feet. Southwestward from McCoy it descends continuously from 1,026 feet to 891 feet at Letts Corners and 645 feet at Elizabethtown. Along East White River the altitude is between 630 and 720 feet, the latter height being reached near Taylorsville. Between East White and White rivers few, if any, altitudes exceed 850 feet, though neighboring hills just outside the border rise above 900 feet. In the valley of White River the altitude is less than 650 feet. West of White River, between Brooklyn and Monrovia, the border skirts an elevated tract which in places rises to about 950 feet, but the Wisconsin drift itself is nowhere found above 850 feet. The altitude declines to about 750 feet at Mill Creek on the line of Morgan and Putnam counties. In Putnam County it fluctuates nearly 200 feet in crossing the ridges and valleys, or from 900 to 700 feet. A prominent hill south of Greencastle, though surrounded by Wisconsin drift, seems not to have been overridden, for the upper 50 feet carries a deposit of white clay, as on ridges outside the limits of the Wisconsin drift. The upper limit of the Wisconsin drift there is about 875 feet. The Wisconsin drift extends nearly 3 miles directly south of this hill and fully a mile southwest, and drops to an altitude along the border more than 100

[1] Elrod, Moses, Report on Decatur County: Twelfth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1882, pp. 140-145.

feet below the top of the hill. In Parke County the altitude is close to 700 feet, but in northwestern Vigo, near Wabash River, it is not much above 600 feet.

CHARACTER.

From Wayne County, Ind., southwestward to the valley of East White River below Columbus, a distance of 75 miles, and for a width of 6 or 8 miles, the surface of the border is gently undulating. Few of the knolls or swells are more than 15 or 20 feet in height, and they may not average more than 10 feet, but they are so numerous and occupy so large a part of the surface as to put this border in decided contrast with the flat tract on its inner or western edge as well as with the plain of older drift on its outer.

West of East White River the knolls are in few places closely aggregated and most of them are small, like those east of the river. For 2 or 3 miles in southeastern Putnam County the border is marked by a low ridge standing 20 to 25 feet above the outer border plain. A considerable part of the border from there northwest to the Wabash Valley in Parke County shows closer grouping of the knolls, many of which are 10 to 20 feet in height.

STRUCTURE OF THE DRIFT.

CONTRAST WITH OUTLYING DRIFT.

The drift of the Wisconsin border in Indiana, though feeble in morainic expression and slight in relief above the outer border district, in structure contrasts strikingly with the outlying drift. Being relatively thin, in most places measuring but 10 to 20 feet, it may be compared at numerous points with the underlying drift. Indeed, few regions afford so good an opportunity for contrasting the Illinoian and Wisconsin drift sheets.

The outlying district shows a weathered till sheet capped by a thin deposit of light-colored pebbleless silt or white clay, generally but 3 to 5 feet in depth. The same weathered till sheet in places capped by its silt is exposed beneath the Wisconsin drift in numerous ravines.

WEATHERING.

The weathering of the surface of the Wisconsin drift sheet is decidedly less than that of the upper part of the Illinoian drift buried beneath it. In the Wisconsin drift small pieces of limestone are still present at the surface, but in the Illinoian they have been dissolved or leached out by percolating waters to a depth usually of several feet. The weathered portion of the Illinoian is a darker brown than the Wisconsin, and is tinged with red, apparently by the high oxidation of the iron. This tinge is rarely found in the Wisconsin drift surface. The Illinoian till has become partly cemented by the deposition apparently of calcareous and ferruginous material through the agency of percolating waters, but the Wisconsin seldom shows cementation. In consequence of this cementation it is much more difficult to excavate the Illinoian than the Wisconsin till. Cementation of itself is not everywhere a proof of the great age of the till, but where the lower drift sheet is cemented and the upper uncemented it corroborates other evidence to that effect. Moreover, this partly cemented lower drift can be traced continuously from beneath the newer drift into the outer border district and is found to be about equally cemented in both situations. This proves that the cementing material was not derived from the overlying Wisconsin drift, and that cementation was probably largely effected before the deposition of the latter.

BURIED SOIL.

The presence of a buried soil under the Wisconsin drift is a matter of common observation, not only along the Wisconsin drift border but throughout the northern half of Indiana and in neighboring States. In Elrod's report on Decatur County[1] the following statements appear:

> The black soil bed is generally present where the bowlder clay and the yellow clay form a junction. It has never been reported as occurring in or under the blue bowlder clay[2] or its equivalent, the white clay of the "flat woods."

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[1] Twelfth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1882, p. 142.
[2] Probably the partly cemented blue bowlder clay of Illinoian age.

Mr. Frank Galbraith, an intelligent observer, who has dug 11 wells in the west part of Clay Township, reports the succession to be: Soil, yellow clay and gravel, black soil frequently with buried timber, and blue clay. Mr. Enos Woodruff, in sinking two wells in the north part of Jackson Township, reports the same strata. Mr. James Bannister, of Alert, has dug four wells and found the black soil in all and timber in part of them. Buried timber is generally found in sinking wells about Newburg, on Sand Creek, and in the vicinity of Clarksburg. The finding of buried timber several feet below the surface is a phenomenon so striking to the average mind that inquiry develops the fact in all neighborhoods where the yellow clay is not replaced by sand or gravel, and frequent as the finding of timber may be, it is not nearly so often noted as the more frequent occurrence of the black soil. In thickness it ranges from 2 to 8 feet, most usually about 2 feet. In physical appearance it more nearly resembles the blue bowlder clay, and where it has apparently been disturbed at some time in its history it is mixed with gravel. Its depth below the surface ranges from 15 to 36 feet.

Most of the buried soil so commonly reported in wells is probably the Sangamon soil developed at the top of the Illinoian drift, for well drillers usually report pebbles either in or immediately underlying it. In all exposures along ravines in Decatur County in the vicinity of Greensburg the black soil was found at the top of the Illinoian till, and in some the white clay above it is still present. The till beneath the buried soil, wherever observed by the writer, is oxidized to a depth of several feet.

The record of a well near Letts Corners, obtained from the well digger, shows a black soil at a greater depth than the exposures along streams would lead one to look for it. The lower part of the section is also different from the customary bluff exposures. The well did not reach rock at 83 feet, though rock is struck in neighboring wells at 20 to 30 feet. It appears, therefore, to be in the line of an old valley. The lower beds may be alluvium, as suggested in the following section:

Section of Mitchell well, 3 miles west of Letts Corners.

	Feet.
Clay, yellow, pebbly (Wisconsin till)	8
Clay, blue, pebbly (Wisconsin till?)	45
Clay, greenish (perhaps alluvium)	6–8
Soil, black, with pebbles (Sangamon or perhaps alluvium)	3–4
Clay, greenish, no pebbles noted (Illinoian or perhaps alluvium)	12
Sand, thin.	
Clay, reddish	7–8
	85

BOWLDERS.

Surface bowlders are common all along the border and, as already suggested, serve to distinguish the Wisconsin from the outlying silt-covered drift, even where the former carries a considerable admixture of silt. They are scarcely so numerous at the border as they are in certain belts which traverse the inner border district (p. 84), but they are not less numerous than over most of the region covered by the Wisconsin drift. Most of them are of granite and are subangular rather than well rounded and do not show glaciated surfaces to such a marked degree as do the rocks contained within the till. This scarcity of glaciated surfaces characterizes the surface bowlders throughout much of the Wisconsin drift area in Indiana and in neighboring States.

In secs. 8, 9, 15, and 22, Nineveh Township, there are 40-acre lots upon which 1,000 or more good-sized bowlders dot the surface; several in secs. 15 and 22 are 10 to 12 feet in diameter. The disregard of surface elevation in their distribution is interesting. The belt in secs. 8 and 9 is on ground 50 to 75 feet higher than in secs. 15 and 22, and in adjoining sections bowlders abound both on the hills and in the valleys. This is mentioned as evidence that the present surface is essentially the same as that left by the glacier, an interpretation that opposes the view of D. S. McCaslin,[1] who held that in a number of localities heavy removal of clay was revealed by the abundance of surface bowlders, and who cited sec. 16, Nineveh Township, as a conspicuous example. McCaslin made a similar incorrect interpretation of a belt of bowlders along a moraine in the northern part of the county.

[1] Thirteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1884, p. 124.

THICKNESS.

Average thickness.—In places the border of the Wisconsin drift is reduced to a mere sprinkling of pebbles and bowlders, commingled with the white clay and weathered portion of the Illinoian drift; but commonly it is a sheet 10 to 20 feet thick, the upper 8 or 10 feet of a fresh yellowish brown and the remainder of a yellowish gray or blue-gray. Till forms the greater part of the border of the Wisconsin drift sheet, yet nearly every farm shows sandy or gravelly spots, and many wells that are carried to the bottom of the Wisconsin drift pass through thin beds of sand.

Sections of wells [1] in the region traversed by the Wisconsin drift border in Indiana show variation in the depth of the glacial deposits but throw little light on the Wisconsin drift as a distinct sheet. Abundant data on this subject may, however, be obtained by examining the bluffs of streams or the sides of excavations. These, as already indicated, show the thickness to be ordinarily but 10 to 20 feet and the bulk of the deposit to be till.

Well data.—The records of most of the wells along the Wisconsin drift border are not sufficiently definite to fix the line between the Wisconsin and pre-Wisconsin drift. They are, however, of value in showing the total thickness and the variable characteristics of the drift.

In the head of the reentrant between the Miami and East White River lobes, from the vicinity of Cambridge and Dublin northward, the wells penetrate thick beds of sand and gravel and only minor amounts of till. Southward from these villages the amount of till increases, and in Rush County the border district has only thin beds of sand and gravel between the till sheets. Thus Elrod [2] reports that a well at the planing mill at Glenwood in eastern Rush County penetrated 116 feet of drift, all of which except 24 feet of fine sand from 66 to 90 feet was till. Blue till was entered at 8 feet and continued to the sand, below which there was an indurated blue hardpan, probably Illinoian. At Rushville the wells penetrate 40 to 90 feet of drift, largely blue till, though in some places containing thin beds of sand and gravel.

Elrod noted the occurrence of a buried soil and peat bed in the vicinity of Milroy in Rush County at a depth of 25 to 30 feet. He gives the following average section for that locality: [3]

Average section of wells at Milroy, Ind.

	Feet.
Soil	1–2
Clay, yellow	10
Clay, blue; replaced in some wells by sand	8–10
Clay, gray, and hardpan, usually mixed with fragments of chert and pebbles	6–8
Gravel, sand, or muck, water bearing; two wells yielded fair specimens of peat	3–5
	28–35

Wells in Decatur County show no records of especial note, but ravines afford numerous opportunities to compare the Wisconsin drift with the underlying older drift. Copper nuggets have been found along ravines in the vicinity of Milford. It was not definitely settled that they came from the older drift, but it was supposed that they did, as the older drift is known to contain copper in the southeastern counties of Indiana outside the limits of the Wisconsin drift. Should such nuggets be found in the Wisconsin drift of this region they might easily have been derived from the older deposit.

No well records of especial note were obtained in Shelby County except those in the channels traversing the southwestern part of the county. These show that the gravel is of moderate depth, till being struck not far below the level of the beds of the present streams. The filling of glacial gravel at Edinburg in southeastern Johnson County is shown by the wells to be about 30 to 40 feet. The total depth of drift, as shown by a gas boring, is 115 feet.

Wells in the vicinity of Morgantown obtain water at 18 to 20 feet from gravel below the Wisconsin drift, but a gas boring penetrated 175 feet of drift, largely sand and gravel.

[1] See county reports of Indiana Surveys; also Water-Supply Paper U. S. Geol. Survey No. 26, 1899.
[2] Fourteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1884, p. 55.
[3] Thirteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1883, p. 103.

At Monrovia most wells obtain water at about 20 feet in sand underlying till of Wisconsin age. A well sunk by David Miller to a depth of 118 feet passed mainly through blue till thought to be Illinoian. West of Monrovia in the northwest part of Morgan County is a level tract in which wells 10 to 20 feet commonly penetrate a few feet of surface sand and a sheet of till before entering the water-bearing sand.

At Stilesville, in southwestern Hendricks County, the drift is 120 to 130 feet thick. The schoolhouse well and the public well enter a hard blue till, probably Illinoian drift, at about 40 feet.

Near New Maysville, in Putnam County, several wells have passed at about 20 feet through a buried soil which apparently lies between the Wisconsin and Illinoian drifts. With the soil are muck and leaves, showing that the pre-Wisconsin surface was swampy.

OUTWASH.

The Wisconsin drift border in Indiana, like that in Illinois,[1] appears to have had remarkably weak outwash. Thin deposits of fine sand occur along the valley of Little Sand Creek and of northern tributaries of Sand Creek which lead away from the Wisconsin border in southern Bartholomew and Jennings counties. These are probably a glacial outwash, though they may be in part a deposit of the streams in later times. But nothing found along the valleys of the large rivers, the East White and White, seems clearly referable to drainage at the maximum limits of the Wisconsin glaciation. Each valley carries a gravel plain, but much of the gravel has been brought from the moraines which cross the streams farther north. These gravel plains not only head well within the Wisconsin drift border, but they occupy valleys that had been cut down in the vicinity of the Wisconsin border below the level of the base of the Wisconsin drift prior to the deposition of this coarse gravelly material. Mill Creek and Walnut Creek and smaller streams that flow away from this Wisconsin drift border show little or no evidence of vigorous discharge down their valleys.

In explanation of this apparent weakness of discharge on the ice border Chamberlin[2] has suggested that at the culmination of the Wisconsin stage of glaciation arid conditions may have prevailed to such an extent as to favor evaporating rather than melting or liquefying of this marginal portion of the ice sheet, and that evaporation gave place to liquefaction as humidity increased.

INNER BORDER.

GENERAL FEATURES.

For a few miles back from the Wisconsin drift border the surface is generally plane or bears only scattered knolls. It shows, however, two undulating strips and two well-defined eskers that seem worthy of mention. These features are somewhat isolated, though one of the eskers terminates in one of the undulating belts. The undulating belts, though probably formed along the margin of the receding ice sheet, are not attended by definite outwash plains or by other confirmative evidence, and their trend is somewhat out of harmony with neighboring bowlder belts. Possibly they were formed submarginally while the ice still covered the district outside.

Ravines which cut down through the Wisconsin drift, as well as borings which pass through it into the older drift, show it to be relatively thin everywhere near the border. Its thickness is generally less than 30 feet and is often but 10 to 20 feet or less. A buried soil underlies it at depths of 20 to 30 feet at a good many points 15 to 20 miles or more inside as well as along or near the border. The underlying older drift attains great thickness along the lines of old valleys, but on the interfluvial tracts is not much thicker than the Wisconsin drift. The above statements are supported by numerous data obtained from well records.

The greatly preponderating material of the drift of this region is a till, which is commonly compact and clayey rather than loose textured and sandy, and which is consequently only slowly pervious to water. Strips of sand and gravel which head in moraines to the north and

[1] Mon. U. S. Geol. Survey, vol. 38, 1899, p. 208.
[2] Remarks made at the Washington meeting of the Geological Society of America, January, 1903.

lead down valleys that traverse this district properly belong to the moraines in which they head. The gravel and sand seems to have been deposited in large part after the ice sheet had withdrawn from this district. Some of the larger and steeper knolls contain gravel deposits and the eskers are composed mainly of gravel, but except in these surface gravel is rare. Beds of sand and gravel incorporated in the till are of small extent.

ST. OMAR-HOPE UNDULATING STRIP.

A strip of undulating drift about 15 miles long and 2 miles wide leads from near St. Omar in northwestern Decatur County southwestward across southeastern Shelby County to the village of Hope in Bartholomew County. It is crossed by Flat Rock Creek in Shelby County. The portion on the north side of the creek includes sharp knolls 25 to 30 feet high. South of the creek these are rare, but the wavy surface puts the strip in contrast with the flat tracts on either side.

Just outside this strip near the village of Adams a kame or gravel knoll, which is the most prominent glacial feature in Decatur County, rises 60 feet or more above the surrounding plain. Though composed largely of gravel, it has a coating of till several feet thick. The Burney esker, discussed below, also lies just outside this undulating strip.

BURNEY ESKER.

The Burney esker northwest of Burney in western Decatur County was noted and described by Elrod[1] under the name "hogback." It extends southward about 2 miles from sec. 5, T. 10 N., R. 8 E., into the northeast part of sec. 17. Clifty Creek crosses it in the southeast quarter of sec. 5. The esker ranges from 10 to 25 feet in height and is single, except in sec. 8, where it is double for half a mile, inclosing a swampy tract about 100 yards wide. It is not accompanied by a channel or esker trough, nor does it have a fan or delta at its southern end.

The esker consists of very coarse material, its northern portion including bowlderets and cobblestones as well as gravel, and its southern portion gravel of medium coarseness. The surface deposits are on the whole coarser than the basal ones, which include considerable sand. The pebbles, both coarse and fine, are largely limestone derived apparently from the rock formations of the region. There is a tendency to bedding in conformity with the upper surface, with a dip down the slope from the crest. Such bedding is explained, on the ice-tunnel hypothesis, by the melting of the supporting ice from beneath the upper beds at the sides of the tunnel which allows them to drop down over the lower beds.

MALTA UNDULATING STRIP.

A gently undulating tract about 15 miles in length and 1 to 3 miles in width leads from near Malta in Putnam County eastward to Reno in Hendricks County, and thence southeastward past Stilesville. Its knolls are commonly but 10 to 15 feet high and are closely clustered in but few places, there being usually but a few knolls to a square mile. This undulating strip may mark the position of the ice margin at a brief halt in its withdrawal from this region.

MALTA ESKER.

The Malta esker is a ridge about 3 miles in length, which sets in on the west bluff of Clear Creek in sec. 23, T. 15 N., R. 3 W., and runs south-southwest along the edge of the valley and across sec. 27 to Warford Fork in sec. 34, where it makes an abrupt turn to east of south and ends at the south side of the valley of Warford Fork in a cluster of gravel knolls in the edge of the Malta undulating belt, about a mile north of Malta. Clear Creek crosses it through a gap about a mile south of its beginning in sec. 23.

For about a mile at the north end the esker consists of a string of low gravelly ridges scarcely 10 feet high, with gaps of considerable width. South of Clear Creek it is more prominent and is nearly continuous to Warford Fork, with a height of 10 to 30 feet and a width of 50 to 75 yards. It does not occupy a well-defined trough or channel but has its base at the level of the bordering till plain.

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[1] Twelfth Ann. Rept. Indiana Geol. Survey, for 1882, pp. 143-144.

The esker consists chiefly of gravel, but it has some till-covered slopes and seems to be made up largely of till for a short distance north of Warford Fork, though maintaining the form presented by the gravelly portion. The drift under the esker as exposed by Clear Creek and Warford Fork is a clayey till.

ST. PAUL-HARTSVILLE BOWLDER BELT.

Bowlders are distributed in small numbers throughout the border district and are especially numerous in certain well-defined narrow belts. Of these belts one of the best defined in southeastern Shelby and the adjacent parts of Decatur and Bartholomew counties is known as the St. Paul-Hartsville bowlder belt, since it runs from one of these villages to the other and extends but little beyond either village. It is about 15 miles long and 2 or 3 miles wide and has somewhat definite limits, there being several times as many bowlders for a given area within it as are found on the bordering districts. At its northern end this bowlder belt is closely associated with the undulating till tract leading southwest from St. Paul to Hope, but within a short distance it turns southward into the plain and ends several miles away from the undulating tract. It is possible that both the bowlder belt and the undulating tract mark positions held by the ice margin, but if they do the margin must have remained stationary at St. Paul while it withdrew several miles from Hartsville to Hope. This appears somewhat unnatural and leaves the interpretation of the relation of the bowlder belt to the undulating tract and of each to the ice margin unsettled. In this bowlder belt, as well as elsewhere in the border region, the bowlders are mainly granite and are from a foot or less up to several feet in diameter.

Bowlders are very numerous in a small tract in Nineveh Township in southern Johnson County. They are especially numerous in secs. 8, 9, 15, and 16, on the brow of a sandstone hill which stands 75 to 100 feet or more above the plane tracts north and east, but they are also common on these plane tracts.

In the western part of the border district bowlders are conspicuous at only a few places. Perhaps the most conspicuous occurrence is in the vicinity of Groveland and near Marysville, in Putnam County, where they abound over an area of several square miles. They are not scarce in any part of the till plain in northeastern Putnam, western Hendricks, and southern Montgomery counties, and generally are plentiful enough to supply the needs of the residents for building in localities where limestone and sandstone are not present.

STRIÆ NEAR BORDER.

Striæ that seem referable to the Wisconsin ice invasion have been observed in several places in Indiana inside the limits of the Wisconsin drift within a few miles of the border. They bear toward the Wisconsin border and cross older striæ at large angles. In the district between Kankakee and Wabash rivers four occurrences with westward bearing are referred to the Wisconsin, and others with southward bearing are referred to earlier movements. Striæ that bear southwestward along the Sugar Creek Valley in northern Montgomery County are referred to the latest movement and others that bear southeastward and southward are referred to earlier movements. Near Greencastle several occurrences with southwestward bearing are probably referable to the Wisconsin stage and others with southward bearing seem referable to an earlier stage of glaciation. In one place on the top of Cemetery Hill, south of Greencastle, southward-bearing striæ occur above the level reached by the Wisconsin drift. Southward-bearing striæ noted by Collett in a railway cut north of Greencastle seem likely to be the product of glaciation earlier than the Wisconsin. Striæ a few miles northwest of Greencastle in sec. 30, T. 15 N., R. 5 W., stand at the very border of the Wisconsin drift. They bear about S. 20° W., which is nearly at right angles with the trend of the part of the Wisconsin border in which they occur and is somewhat divergent from the southward-bearing striæ of the earlier invasion found in that region. Some local deflection of the earlier movement may, however, have given them this bearing. Striæ in the bluff of Clifty Creek, west of Hartsville, Bartholomew County, are directed southeastward toward the Wisconsin border and seem likely to have been formed at

the Wisconsin invasion. They are light but cover a convex surface which was polished smoothly. The table below includes all recorded observations near the limits of the Wisconsin drift in Indiana, whether of the Wisconsin or earlier glaciation.

Glacial striæ in Indiana.

Locality.	Bearing.[a]	Observer.	Probable age.
Quarry 3 miles southeast of Kentland	S. 77° W	Chamberlin	Wisconsin.
In same quarry	S. 7° E	do	Illinoian.
Monon	S. 85° W	do	Wisconsin.
Do	S. 34° E	do	Illinoian.
Rensselaer	S. 8°-14° W	Purdue	Wisconsin.
Rainsville	Westerly	Chamberlin	Do.
2 miles east of Williamsport	do	do	Do.
Williamsport	S. 8°-10° W	Salisbury	Illinoian(?).
Do	S. 68° E	Leverett	Wisconsin.[b]
Near Darlington	Southwest	Thompson	Wisconsin.
Do	S. 8° E	Collett	Illinoian.
Near Darlington (3 occurrences)	S. 27° 50′ E; S. 23° 50′ E; S. 22° 30′ E	Coulter[a]	Illinoian(?).
Near Darlington	S. 31° E	Leverett	Do.
Near Troutman	S. 8° E	Collett	Do.
Do	S. 10° W	Beachler	Do.
Sec. 20, T. 15 N., R. 5 W	S. 20° W	Campbell	Wisconsin(?).
Sec. 27, T. 15 N., R. 6 W	S. 12° W	do	Wisconsin.
Sec. 1, T. 15 N., R. 7 W	S. 27°-39° W	do	Do.
Sec. 21, T. 16 N., R. 7 W	S. 70° 30′ W	do	Do.
Sec. 24, T. 16 N., R. 7 W	S. 28° W	do	Do.
Sec. 25, T. 16 N., R. 7 W	S. 56° W	do	Do.
Railroad cut near Maple Grove	S. 10° W	Collett	Illinoian.
Greencastle	Southward	Brown	Do.
Greencastle, southwestern part	S. 28°-48° W	Chamberlin	Wisconsin.
Do	S. 40° W	Leverett	Do.
Greencastle, Cemetery Hill	Southward	Brown	Illinoian.
West of Hartsville	S. 32°-35° E	Leverett	Wisconsin.

[a] All observations have magnetic bearing except those of Coulter, which are corrected to the true meridian. [b] From Lake Michigan lobe?

GLACIAL DRAINAGE.

Traces of drainage systems which depart somewhat from the present systems are found in the eastern part of the border district. The principal headwater branch of East White River, locally called Blue River, and Flat Rock Creek, the stream next in importance, utilize part of a complex system of valleys which cut the country they traverse into large island-like tracts. This network of channels appears to have been developed on flat plains in which preglacial drainage lines had been obliterated and new lines had to be opened upon the retreat of the ice sheet. The channels mark the rambling courses taken by streams before they had become established in the present lines.

Some of the peculiarities of drainage displayed by Flat Rock Creek were noted and discussed some years since by C. S. Beachler.[1] The branching channels and the several islands inclosed by them were noted and their boundaries mapped approximately by Collett in his report on Shelby County.[2] They were interpreted to be the lines of discharge of streams which had their source in the retreating ice sheet. Collett called attention to the presence of gravel and sand to a depth of about 35 feet below the broad bottoms of this system of branching channels and interpreted these deposits to be due to a grading up or partial refilling of the channels by the outwash from the ice sheet.

The grading up which the valleys experienced implies a large amount of preceding erosion. The removal of this gravel filling would give the valleys a depth of 50 to 75 feet or more and a combined width of 2 to 6 miles in their course through Shelby and Bartholomew counties. Notwithstanding the fact that this wide cutting has been done not in rock but in glacial deposits its amount appears very great to have been effected in connection with the recession of the ice in the Wisconsin stage. It seems more nearly in harmony with post-Illinoian erosion.

An examination of the bluffs of these valleys and of the tracts inclosed by the branching channels shows that the general level of the surface of the older or Illinoian drift is higher than the gravel filling in the valleys for at least as far up the valleys as the vicinity of Shelbyville if

[1] An abandoned Pleistocene river channel in eastern Indiana: Jour. Geology, vol. 2, 1894, pp. 62-65.
[2] Eleventh Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1881, map opposite p. 55.

not as far as Newcastle. This older drift is easily recognized below Shelbyville, for its outcrops are numerous and extensive, but above Shelbyville its exposures are rare and of small extent and some uncertainty is felt as to its upper limit. In addition to its occurrence in the Mount Auburn ridge, older drift lies on the border of the East White Valley about 25 feet above the gravel filling in a plain that slopes southward at about the same rate as the valley filling. The Wisconsin drift forms only a thin coating 10 to 25 feet thick on these bluffs and on the inclosed tracts between the channels, and there seem to be no grounds for assuming that its thickness is much greater inside the valleys.

On this interpretation of pre-Wisconsin excavation some difficulty may be found in accounting for the network of valleys. There would seem, however, to have been fully as favorable conditions for the development of such a network on the withdrawal of the Illinoian as on that of a succeeding ice sheet, for the slopes or attitude of the surface appear not to have been markedly different in the two stages. The branching, as in the Flat Rock drainage, seems to have arisen through stream wanderings over a flat tract on which there were no guiding channels. As the earlier drift in this region is much thicker than the Wisconsin it may have more completely effaced the channels which preceded its deposition.

CHAPTER V.

CORRELATIVES OF THE CHAMPAIGN MORAINIC SYSTEM.

By Frank Leverett.

INTERPRETATION.

The outer (or main) moraine and the second moraine of the Champaign morainic system of the Illinois lobe were traced in Monograph XXXVIII to western Montgomery County, Ind., where they connected at a sharp angle with a morainic system coming up from the southeast. The outer moraine connected about 6 miles west of Crawfordsville, near the village of Wesley, and the second moraine about 6 miles farther north, immediately north of Waynetown. At the time the earlier monograph was written the morainic system trending northwest was supposed to override and conceal the northward continuation of the Champaign system. It was referred to the later Wisconsin and the Champaign was referred to the earlier Wisconsin.

The reference of the northwest-trending morainic system to the later Wisconsin was made not because of positive evidence of overriding but rather as a consequence of the bowlder belts of Warren and Benton counties, which suggested that the Huron-Erie part of the Labrador ice field occupied the vicinity of the junction of the two lobes later than the Illinois lobe. The bowlder belt does not, however, come down to this morainic system but lies a few miles east of it and diverges still farther toward the southeast. After the publication of Monograph XXXVIII the writer revisited the locality and studied quite widely in Montgomery and neighboring counties, aiming to gather all the available evidence on the relation of these moraines to each other and to the moraines and bowlder belts farther north and east. Outwash and drainage features that would throw light on the history were diligently sought, but were found singularly lacking even in the reentrant between the Illinois lobe and the lobe to the east as well as along the west side of the combined belt north of the junction of the moraines. The moraines become merged at their junction into a single belt without definite evidence of difference in the date of deposition, and without outwash from one lobe into the territory of the other. Mention should perhaps be made of a peculiarity of the headwater branches of Coal Creek that lead westward from the combined morainic system just north of the point of union. These branches flow in broad shallow sags nearly half a mile wide and only 15 to 20 feet deep, which were at first suspected to represent erosion by glacial drainage leading westward from the moraine and thus to support the theory of later occupancy by the eastern ice lobe. But further examination showed that the sags lack well-defined banks or bluffs and may have been developed by subglacial drainage. As the matter now stands nothing definite can be cited to prove that the two morainic systems are of different ages. It seems best, therefore, to adopt the simpler alternative and to consider them as probable correlatives.

A chain of undulating belts leading from the junction of the two moraines in western Indiana to the reentrant between the East White and Miami lobes in eastern Indiana may together form a correlative of the Champaign morainic system of the Illinois lobe, though gaps of considerable width in which nothing of morainic aspect was discovered intervene between some of the links. Each of the undulating strips represents the first stand made by the ice after it retreated from the Wisconsin drift border.

COURSE AND DISTRIBUTION.

The course of the outer moraine of the Champaign system having been outlined in Monograph XXXVIII up to the point of junction with the supposed correlative west of Crawfordsville, only the moraines east of the reentrant angle need be discussed. Beginning at the north-

west end of the supposed interlobate spur a few miles northwest of Crawfordsville, the moraine runs southward with a width of 3 or 4 miles to the place of junction west of Crawfordsville, passing through Wingate and just east of Waynetown. Beyond the junction it goes southeastward, crossing Sugar Creek at the bend west of Crawfordsville and continuing to Ladoga, keeping south of the Chicago, Indianapolis & Louisville Railway and maintaining a width of about 2 miles.

Near Ladoga it loses its topographic expression, there being a plain to the south and east for 6 to 8 miles, or as far as Walnut Fork of Eel River in northwestern Hendricks County. East of Walnut Fork, near North Salem, an undulating belt which is probably its continuation sets in and leads southeastward to Clayton, a distance of about 15 miles, exhibiting in places a parallel series of ridges of considerable strength spread over a width of 3 or 4 miles. From the southeastern end of this undulating belt a bowldery strip 1 to 2 miles wide leads eastward nearly at right angles to the belt. Whether this marks the trend of the ice border or was developed along the line of recession of the ice is not at present known. The position, however, seems a doubtful one for the ice border.

From Clayton a plain extends southeastward to the White River valley in northwestern Johnson County, a distance of 18 or 20 miles, where another undulating belt, beginning on the east bluff of White River, leads southeastward, passing north of Union village and south of Franklin, to Sugar Creek, a tributary of East White River in eastern Johnson County. As this belt represents the first moraine back from the Wisconsin border in Johnson County, its position corresponds with that of the undulating belt in Hendricks County. These two, therefore, are probable correlatives despite the gap of nearly 20 miles between their ends.

Beyond Sugar Creek another gap intervenes, followed in southern Shelby County by a supposed continuation of the system in a bowldery strip which sets in near Marietta on the east bluff of East White River and extends with slight interruptions, caused by gravel plains and drainage lines, across the southeastern part of the county to Cynthiana, on the east border directly east of Shelbyville, and thence bears northeastward to Rushville. From Rushville a definite ridge runs northward to Newcastle along Flatrock Creek valley, keeping west of the stream except for a few knolls in southern Henry County that are on the east side. The ridge loses its expression near Newcastle within 5 or 6 miles of the head of the reentrant between the East White and Miami lobes.

The moraine and bowlder belt east of East White River from Newcastle to Marietta holds a close parallelism to the Wisconsin border 15 to 20 miles inside that border. In Johnson County it is 8 to 12 miles back of the Wisconsin border, and in Hendricks and Montgomery counties it is 20 to 25 miles back of it

TOPOGRAPHY.

The northwest part of the supposed interlobate spur in northwestern Montgomery County, Ind., contains low knolls and ridges 20 feet or less in height interspersed with basins and flat tracts. In many places the knolls are clustered, giving the surface a very hummocky aspect. A slight tendency to ridging in the line of the moraine was noted. Southward from Elmdale the knolls and ridges are distributed along two lines between which is a tract about a mile wide with only a few knolls. Some ridges and knolls on the eastern line reach 25 to 30 feet, and a single knoll southeast of Elmdale rises to 50 or 60 feet; the great majority along both lines are, however, 20 feet or less in height.

Southwest of Crawfordsville, between Sugar Creek and Offield Creek, are narrow ridges 20 to 25 feet high, the more prominent of which trend nearly east and west. Among these are numerous small knolls 5 to 15 feet high. About midway between Crawfordsville and Whitesville gravelly knolls extend like a spur northeastward from the inner border of the moraine across secs. 14, 11, and 12, T. 18 N., R. 4 W. The largest knoll is 30 feet in height; the others are only about 15 feet. Aside from this spur the moraine south and southeast from Crawfordsville carries only low knolls 6 to 15 feet high, and this weak expression continues nearly to Ladoga. A few sharp gravel knolls 15 to 25 feet high, both east and south of Ladoga, on the borders of the Raccoon Creek valley, form the terminus of the undulating strip.

The supposed continuation in northwestern Hendricks County has a very mild expression from North Salem southeastward for 5 or 6 miles, consisting merely of a wavy surface in which the swells rise 10 to 25 feet above the sags. Near Milledgeville the inner border has sharp knolls 15 to 25 feet or more high, but is otherwise weak. A well-defined ridge sets in about midway between North Salem and Danville and, except for a slight gap 2 miles northwest of Danville, continues to that city. Where most prominent the ridge is not less than 50 feet in height and yet is scarcely one-fourth mile in width; through most of its length, however, it is but 20 to 25 feet high. West of this ridge another 2 miles in length ends on the south about 2½ miles west of Danville; it also has a width of only one-fourth mile and yet in places rises 50 feet above the level of the plain to the west. East of these ridges are lower ones with less continuity, some of them being slightly elongated knolls, but all conforming to the northwest-southeast trend of the moraine.

East of Hadley a series of several sharp ridges, individually 1 or 2 miles long with gaps of half a mile, fills in the space of 4 miles between Hadley and Danville. The width of the ridges is one-fourth mile or less and their height only 15 to 25 feet. This morainic belt fades out in the vicinity of the valley of East Fork of Mill Creek, except that a narrow strip of undulating land continues southward along the divide between Mill Creek and West White Lick Creek about to Clayton.

The moraine in northwestern Johnson County covers a width of 1 to 4 miles and for part of its course occupies the divide between streams flowing westward or southwestward to White River and eastward to Youngs Creek, a tributary of East White River. East of Youngs Creek the moraine is only about a mile wide. In western Johnson County a slight ridge with an outer border relief of 15 to 20 feet is present for a few miles, but aside from this the moraine consists of a series of loosely connected low swells. In the tract east of Franklin knolls are conspicuous, several rising abruptly to heights of 30 to 40 feet. North of the moraine is a till plain bearing scattered sharp knolls, and a well-defined esker having its southern terminus in the moraine (p. 93). The most prominent knoll, Donnell Mound (in sec. 8, T. 12 N., R. 4 E.), rises 90 feet above bordering low ground and is slightly elliptical, with its longer axis from northeast to southwest, or about at a right angle with the moraine. Doty Mound (sec. 16, T. 13 N., R. 3 E.) is not less than 75 feet in height and has very steep slopes.

The moraine at Rushville and the bowlder belt which constitutes its westward continuation are thought to be the continuation of the chain of moraines. In Shelby County the bowlder belt is unattended by conspicuous knolls, except at the northern end of Mount Auburn Ridge, where several sharp gravel knolls may be of Wisconsin age; but from the vicinity of Rushville northward it is combined with a well-defined moraine. It does not connect closely with the eastern end of the Johnson County undulating strip, but appears about 5 miles southeast of the latter on the opposite side of the great gravel plain of East White River. It leads down the eastern slope of the Mount Auburn Ridge from its northern end nearly to Mount Auburn, or for about 5 miles, and is traceable to the edge of a slough that forms one of the numerous channels cut in the drift of Shelby County. It reappears east of this slough at Lewis Creek station and is traceable northeastward to Cynthiana, where a few low knolls appear, beyond which it is attended by scattered knolls northeastward to Rushville. For 6 to 7 miles north from Rushville, or about to Hamilton station, there is a morainic ridge scarcely a mile in width with undulating surface and abrupt outer border relief. Farther north this ridge spreads out to about 2 miles and is less definitely ridged; most of its knolls are but 15 to 20 feet high, but a group of them in secs. 16 and 21, T. 15 N., R. 10 E., is more prominent and includes one that rises to 70 feet.

STRUCTURE OF THE DRIFT.

COMPOSITION.

Along the chain of moraines the prevailing surface portion of the drift is bowlder clay, in which pockets of water-bearing sand and gravel are so common that many wells are obtained at depths of 12 to 20 feet. The water-bearing beds do not appear to form continuous sheets;

they occur at various horizons and seem to be of small horizontal and vertical extent. Gravel knolls are scattered along the entire length of the chain of moraines and are conspicuous, though they occupy but a very small part of the surface.

Surface bowlders are very unequally distributed, being hard to find in some places and conspicuous in others. On the supposed interlobate spur and also south of Sugar Creek in western Montgomery County they are numerous, and in southeastern Montgomery and northern Hendricks counties they are rare. The two larger ridges northwest of Danville and the moraine in Johnson County are thickly strewn with them, and in the district east of East White River they form a bowlder belt. More than 95 per cent of all the bowlders are of granite.

In order to compare the classes of rock found in the till and in the gravel with the surface bowlders, samples of pebbles or small pieces of rock an inch or less in diameter were collected in a bowldery portion of the drift in Johnson County and classified with the results shown in the table below. This table, though revealing striking similarity in the rock constituents of the till and of the gravel, shows striking dissimilarity between these and the surface bowlders. Glacial deposits have not been found to contain a large percentage of granite rocks except on the surface, either in this district or in other parts of the region south of the Great Lakes.

The first set of pebbles in the table is from the bluff of White River from a kame which appears to be of pre-Wisconsin age; the second set is from Donnell Mound; and the third and fourth sets are from an esker and a till plain, all of Wisconsin age.

Percentage of different rock types in glacial deposits in central Indiana.

	Pre-Wisconsin.	Wisconsin.		
	Kame on White River.	Donnell Mound (kame).	Franklin esker.	Till plain.
Crystalline, mainly granite	19.2	24.1	21.5	17.0
Sandstone	1.3	.0	.0	.0
Shale	5.1	6.6	.0	13.4
Chert	16.66	18.1	22.17	.0
Limestone (including dolomite)	57.7	51.8	56.3	69.5
	99.96	99.9	99.97	99.9
Number of pebbles classified	78	116	158	82

THICKNESS.

Variations.—Changes in the thickness of the drift are interesting and abrupt. In central and southeastern Montgomery County rock is exposed along many of the small ravines at about 25 feet below the uplands, and it is usually struck at moderate depths from Crawfordsville northwestward. In the vicinity of Crawfordsville, in a buried channel, the drift is over 200 feet thick. In central and northern Hendricks County it is so thick that wells 60 to 80 feet in depth do not reach the rock, but in southern Hendricks County rock is exposed in shallow ravines and is reached by wells at 20 feet or less. The knolls and ridges are composed wholly of drift.

Pre-Wisconsin drift.—It is rather difficult to determine how much of the drift in Montgomery and Hendricks counties is referable to the Wisconsin invasion. It may not greatly exceed the amount comprised in the knolls and ridges. In Crawfordsville, however, a buried soil was found between drift sheets at a depth of 80 to 90 feet, as reported by Owen,[1] and similar soil was found at several other places a few miles east of Crawfordsville in Boone County at depths of 45 to 65 feet.

In Johnson County the moraine begins in the western part of the county where the drift is rather thin, but runs into thick drift in the eastern part. It is probable, however, that only a few feet of the drift below the level of the base of the knolls is referable to the Wisconsin invasion. East of East White River in Rush and Henry counties the moraine is in a region presenting great differences in the thickness of the drift, the depth to rock ranging from

[1] Ann. Rept. Indiana Geol. Survey for 1859-60, p. 133.

30 feet to 300 feet or more. The drift pertaining to the Wisconsin invasion, however, may not exceed 30 feet in average thickness, for the preglacial valleys were largely filled at earlier stages of glaciation.

Well data.—The Crawfordsville gas-well boring at the railway junction in the southeast part of the city has the following drift section, as observed and reported by C. S. Beachler. It is probable that the lower or hard bed of blue clay is of pre-Wisconsin age.

Section of drift in Crawfordsville gas boring.

	Feet.
Till, yellow	12
Till, blue, soft	60
Clay, blue, hard, mixed with gravel	64
Gravel	4
	140

About one-half mile east from Crawfordsville, in sec. 33, T. 19 N., R. 4 W., a boring for natural gas penetrated 240 feet of drift; the surface is about 790 feet above sea level or nearly the same as that at the well near Crawfordsville Junction. In the valley of Sugar Creek in the north part of Crawfordsville, about 660 feet above sea level, a gas boring penetrated 150 feet of drift. About a mile north of this gas boring rock outcrops at an altitude of 750 feet or more. The change in the altitude of the rock surface within a mile is therefore about 240 feet. The rock surface rises southeast from Crawfordsville, reaching about 875 feet near New Ross.

In the north part of North Salem, Hendricks County, at an altitude about 910 feet above sea level, a well penetrated 85 feet of drift without reaching rock, and in the west part of the village one 70 feet deep stopped in drift. The gas well at Danville, which began on ground estimated to be 25 feet lower than the depot (and 871 feet above sea level), penetrated 160 feet of drift, of which the upper 43 feet contained much gravel and the remainder was mainly blue till.

The following record of a gas boring was reported by Prof. D. A. Owen, of the Franklin Baptist College:

Section of drift in Franklin gas boring.

	Feet.
Till, yellow and blue	40–45
Sand	±20
Till, blue, alternating with gravel, the till constituting about four-fifths of the material (probably pre-Wisconsin)	100
	170

A well at Mr. Burgess's residence, in Youngs Creek valley south of the courthouse at Franklin, obtains a flow from a depth of 90 feet. A flow was also obtained in the gas-well boring from about the same depth, and there is good evidence of a continuous sheet of water from one well to the other, though they are about 300 yards apart, for the water from the Burgess well became turbid soon after the gas boring began to flow.

Several wells in the north part of Franklin along a small tributary of Youngs Creek obtain flows from 40 to 45 feet, perhaps from between the Wisconsin and pre-Wisconsin drifts; and a well at the water tank of the Cleveland, Cincinnati, Chicago & St. Louis Railway in the valley of Hurricane Creek obtains a flow from about 30 feet. These shallow flowing wells probably have no connection with the Burgess well.

In the southeast part of Franklin, in the vicinity of the starch factory, several wells whose depth is only 20 to 30 feet have a common source of supply, for when an attempt was made to pump one dry the others to a distance of 75 to 100 yards from this well were lowered several feet. There seems, therefore, to be a sheet of sand or gravel below the upper till.

Owen reports the following section of a well at the Baptist College, which stands on a low gravel ridge in Franklin:

Record of well at Baptist College, Franklin, Ind.

	Feet.
Sand and gravel	16-18
Till, blue	±40
Sand, fine	2
Till, blue (probably pre-Wisconsin)	50
Gravel	4
	114

A well on the slope of Donnells Mound in sec. 8, Franklin Township, at a level about 40 feet above the base of the mound, has a depth of 50 feet. It passed through no till, but penetrated gravel to 35 or 40 feet and then entered sand.

Wells in Shelby County, in the vicinity of the bowlder belt, in places reach rock at 50 feet or less. The drift is largely a blue till. Some wells pass at about 30 feet from a soft into a hard till, which is thought to mark the top of the pre-Wisconsin drift. In central and western Rush County most wells reach rock at 50 to 75 feet, though one near Manilla, as reported by Collett,[1] penetrated 93 feet of drift, as follows:

Section of Arbuckle & Mills boring west of Manilla, Ind.

	Feet.
Soil and clay	5
Quicksand	3
Clay, blue	5
Clay and gravel	3
Bowlder clay	17
Sand and gravel	3
Bowlder clay, blue	57
	93

At Rushville the drift may exceed 100 feet in depth on the moraine north of the city, for rock is struck at 40 to 90 feet on the plain east of the moraine. The drift on this plain and apparently also on the moraine is mainly till.

At Hamilton station a gas well penetrated 92 feet of sand and then 55 feet of hard blue till before striking rock.

OUTER BORDER.

The only gravelly outwash noted along the entire chain of moraines is found in the northern part of Rush County in the vicinity of Raleigh. The gravel is spread out over a width of about 2 miles for a length of 5 or 6 miles along the eastern base of the moraine. Several flowing wells about a mile northeast of Raleigh show that the gravel is shallow, for they are mainly through till and obtain water from the sand bed beneath the till at depths ranging from 65 to about 100 feet. A well in Raleigh 80 feet deep has a head within a foot or two of the surface.

INNER BORDER.

TILL PLAIN.

For some miles back from the undulating strips there is a till plain with scattered knolls, few of which exceed 10 feet in height. This plain rises toward the northeast in Montgomery and Boone counties and within a short distance reaches an elevation considerably higher than that of the moraine. In Hendricks County it descends eastward from the moraine. In Johnson County it rises very gradually northward from the moraine, and in the district east of East White River it generally descends from the moraine toward the river across the inner border district. These slopes are not controlled entirely by the altitude of the underlying rock, for the ascent in Johnson, Boone, and Montgomery counties is due to a thickening of the drift.

[1] Eleventh Ann. Rept. Dept. Geology and Nat. Hist. Indiana, 1881, pp. 64-65.

In Johnson County this plain is traversed by shallow northeast-southwest depressions, in which there are chains of elliptical knolls, and in one place an esker. These sags are now occupied by small streams, High Bridge, Indian, and Hurricane creeks. Aside from these the plain carries mounds such as Donnell and Doty mounds, already described, which are conspicuous because of their unusual height.

The drift seems to be largely a clayey till, though pockets and thin beds of gravel and sand in it furnish supplies for wells at shallow depths.

In portions of the plain bowlders are conspicuous. One belt already noted leads from a point near Plainfield in Hendricks County almost to the White River valley at Indianapolis. A very bowldery strip one-fourth mile wide and about 2 miles long lies in the southwest part of T. 13 N., R. 4 W., in Johnson County. Another belt leads southwestward from Arlington in northern Rush County along the northwest side of Little Blue River. Its course is nearly parallel to the moraine and bowlder belt, leading past Rushville, and it may indicate a brief halt of the ice margin in its withdrawal from this region.

FRANKLIN ESKER.

The Franklin esker heads in the southwest part of Franklin and leads southwestward about 3 miles to the inner border of the moraine. At its southwest end it expands into a fan-shaped plain or delta covering about one-fourth of a square mile, around which lies a swampy depression 100 yards or more in width that separates it from the moraine. The esker itself has its head in a swampy tract which extends 2 or 3 miles farther north than the esker and which seems to have been formed by subglacial drainage in connection with it. A few gravel knolls and low ridges 4 to 6 feet high in this trough are apparently referable to the stream which formed the esker.

The esker is opened extensively at its north end, where it consists of fine gravel with considerable sand intermixed. The beds are horizontal with only a slight oblique bedding. The character of the pebbles is shown in the table (p. 90).

The remarkable feature of this esker is its breadth, which in places exceeds one-eighth mile, though its height is only 15 or 20 feet above border tracts. It may, however, have been formed in a very broad tunnel in or beneath the ice sheet.

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Sand, fine	2
Till, blue (probably pre-Wisconsin)	50
Gravel	4
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A well on the slope of Donnells Mound in sec. 8, Franklin Township, at a level about 40 feet above the base of the mound, has a depth of 50 feet. It passed through no till, but penetrated gravel to 35 or 40 feet and then entered sand.

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The only gravelly outwash noted along the entire chain of moraines is found in the northern part of Rush County in the vicinity of Raleigh. The gravel is spread out over a width of about 2 miles for a length of 5 or 6 miles along the eastern base of the moraine. Several flowing wells about a mile northeast of Raleigh show that the gravel is shallow, for they are mainly through till and obtain water from the sand bed beneath the till at depths ranging from 65 to about 100 feet. A well in Raleigh 80 feet deep has a head within a foot or two of the surface.

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In portions of the plain bowlders are conspicuous. One belt already noted leads from a point near Plainfield in Hendricks County almost to the White River valley at Indianapolis. A very bowldery strip one-fourth mile wide and about 2 miles long lies in the southwest part of T. 13 N., R. 4 W., in Johnson County. Another belt leads southwestward from Arlington in northern Rush County along the northwest side of Little Blue River. Its course is nearly parallel to the moraine and bowlder belt, leading past Rushville, and it may indicate a brief halt of the ice margin in its withdrawal from this region.

FRANKLIN ESKER.

The Franklin esker heads in the southwest part of Franklin and leads southwestward about 3 miles to the inner border of the moraine. At its southwest end it expands into a fan-shaped plain or delta covering about one-fourth of a square mile, around which lies a swampy depression 100 yards or more in width that separates it from the moraine. The esker itself has its head in a swampy tract which extends 2 or 3 miles farther north than the esker and which seems to have been formed by subglacial drainage in connection with it. A few gravel knolls and low ridges 4 to 6 feet high in this trough are apparently referable to the stream which formed the esker.

The esker is opened extensively at its north end, where it consists of fine gravel with considerable sand intermixed. The beds are horizontal with only a slight oblique bedding. The character of the pebbles is shown in the table (p. 90).

The remarkable feature of this esker is its breadth, which in places exceeds one-eighth mile, though its height is only 15 or 20 feet above border tracts. It may, however, have been formed in a very broad tunnel in or beneath the ice sheet.

CHAPTER VI.

CORRELATIVES OF THE BLOOMINGTON MORAINIC SYSTEM.

By Frank Leverett.

INTERPRETATION.

The system of moraines to which the name Bloomington is applied is one of the largest developed by the Illinois lobe. It receives its name from the city of Bloomington, Ill., which stands on a prominent portion of the outermost ridge of the system. Where best developed, in eastern Illinois and western Indiana, it consists of four bulky ridges, but west of Illinois River these are merged into a bulky outer ridge and a small inner ridge. This system of moraines has been discussed in Monograph XXXVIII throughout the length of the portion developed by the Illinois lobe. It remains to consider the equivalent of this system produced in Indiana by the Huron-Erie portion of the Labrador ice field.

A massive accumulation of drift running across central Indiana from west to east was brought to notice and briefly discussed by Maurice Thompson as a "Terminal moraine in central Indiana."[1] Thompson recognized the complexity of this belt, for after outlining its course he remarked:

> I have for mere convenience called the morainic mass thus roughly outlined a terminal moraine; but I regard it a cluster or tangle of a number of inseparable moraines, caused chiefly by the separating of the great glacier into lobes and by successive advances and retreats of the ice mass.

COURSE AND DISTRIBUTION.

From the eastern end of the ridges of the Bloomington system, at the reentrant angle in Benton and Warren counties, Ind., the belt of thick drift leads southeastward across Tippecanoe and northern Montgomery, Clinton, and Boone counties into the edge of Tipton County. It there swings southward and passes through southwestern Tipton and western Hamilton and Marion counties, past the city of Indianapolis, its outer part extending into northern Johnson County. From Marion County it runs eastward across Hancock, southeastern Madison, western and northern Henry, southeastern Delaware, southern Randolph, and northern Wayne counties into Ohio. In Randolph and Wayne counties it connects with the "main morainic system" of the Miami lobe discussed in Monograph XLI. In the present report only the part in Indiana will be discussed.

TOPOGRAPHY.

ALTITUDE.

This great drift belt includes the most elevated points in Indiana, which are near the east line of the State in Randolph and Wayne counties and reach 1,250 to 1,285 feet. The lowest parts are on the border of White River near Indianapolis, where the altitude is about 725 feet, and on the border of the Wabash below Lafayette, where it falls slightly below 700 feet. The descent of 500 feet, which the moraine makes from near the Indiana-Ohio line to the White River valley near Indianapolis, is very gradual, the distance being about 70 miles. Between the White and Wabash valleys there is a rise of about 250 feet, or to nearly 1,000 feet. At the reentrant angle west of the Wabash the altitude reaches 850 to 875 feet at the highest points on the ridges near Fowler, but on the plains between the ridges it is scarcely 800 feet.

[1] Fifteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1886, pp. 57-60.

The underlying rock surface shows nearly as much range as the drift surface, being over 1,000 feet near the Indiana-Ohio line, 570 feet in the vicinity of Indianapolis, 750 feet in western Hamilton County, 380 to 400 feet in the Wabash Valley near Lafayette, and from 650 to 760 feet in the vicinity of Fowler.

The altitudes of the drift surface and the rock surface on the inner plain, the drift belt, and the outer plain along several north-south lines are given in the table below. The line through Lynn shows a markedly higher rock surface at the crest of the belt than is found on the tracts lying to the north and south. West of White River the rock surface is much higher outside of than beneath the great drift belt, the drift being banked against the northeast face of a rock escarpment in Hendricks and Montgomery counties. On the line passing through Lafayette a great valley is crossed which leads westward from that city. The line running south from Fowler crosses the same buried valley near the Benton-Warren county line.

Altitude of drift surface and rock surface in cross sections.

Location.	Inner plain.		Crest of the belt.		Outer plain.	
	Drift surface.	Rock surface.	Drift surface.	Rock surface.	Drift surface.	Rock surface.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
State line (Ohio and Indiana)	1,090	908–1,028	1,168	?	1,125	955
Meridian of Lynn	1,089	890–1,000	1,162	1,050	1,100	820–950
Meridian of Losantville	1,100	893	1,128	900	1,075	904
Meridian of Newcastle	950	885–950	1,090	855	1,035	550–830
Meridian of Kennard	910	825	1,041	820	980	752
Meridian of Greenfield	850	760–835	915	700	855	700
Meridian of Cumberland	770	640–715	880	600	775	560
Tipton to New Ross	872	720	988	737	888	868
Franklin to New Ross	850	575	900	580	888	868
Meridian of Lafayette	675	380–655	830	?	785	475–725
Meridian of Fowler	820	660–760	[a] 770–870	310–660	675	650
State line (Indiana and Illinois)	700	660	[a] 730–780	580–610	650	470–550

[a] The crests of the several ridges differ in altitude.

CHARACTER AND RELIEF.

The moraines of the Bloomington system are conspicuous in the vicinity of the reentrant angles where they connect with those of the Illinois lobe in western Indiana and with those of the Miami lobe in eastern Indiana, but are so weak in much of the intervening course that it is difficult to trace them individually across the State. In some places, where ridges and knolls die out, bowlder belts mark the continuation of the ice border, and in some places even these are lacking.

Warren, Fountain, and Tippecanoe counties.—The portion of the belt in the vicinity of the Wabash Valley in eastern Warren, northeastern Fountain, and southwestern Tippecanoe counties comprises about all of it that is prominent east of the reentrant angle in western Indiana. North of the Wabash, in eastern Warren County, two strong moraines, each about 2 miles wide, separated by a nearly plane tract about a mile wide, run northwest and southeast with a billowy surface bearing a close aggregation of knolls whose height ranges from 10 feet or less to about 30 feet. The inner or eastern border of the eastern of these two belts runs from Pine Village toward Independence, leaving about 50 square miles of the northeast corner of Warren County with very flat surface. South of the Wabash, in northeastern Fountain and southwestern Lafayette counties, the morainic development is very irregular. Clusters of sharp knolls covering a square mile or more, surrounded by gently undulating or nearly plane tracts, can be linked into two parallel chains leading eastward and then southeastward into Montgomery County. Some of the knolls in these clusters reach a height of 50 or 60 feet and many reach 30 feet or more. Shawnee Mound, in southwestern Tippecanoe County, rises 60 feet above the surrounding country and 80 feet above the marsh on its northwest border. About 5 miles southeast is Cemetery Hill, also 60 feet high.

In Tippecanoe County a gently undulating surface, extending entirely across the southern townships, is about 100 feet higher than the next range of townships to the north. In places

the descent to this northern plain is abrupt, but as a rule it extends over a distance of 2 miles or more. The east-west trend of the north border of this elevated undulating tract probably conforms to a late position of the ice border during the development of the Bloomington morainic system, or a bowlder belt and weak moraines which are thought to be close successors of the Bloomington system parallel it a few miles to the north. During the early development of the morainic system the ice border seems to have had a northwest-southeast trend and to have passed from southwestern Lafayette County across northeastern Montgomery County.

Montgomery County.—The strong moraines of southwestern Tippecanoe County are paralleled on the inner or northeast border by a gently undulating but very bowldery tract 1 to 2 miles wide which leads from the Wabash Valley near the Fountain-Tippecanoe county line southeastward to Linden, in northern Montgomery County, and thence past Darlington to the eastern edge of the county, about 10 miles east of Crawfordsville, beyond which it is not clearly marked. This tract is commonly known as the Linden-Darlington bowlder belt and is thought to mark a position of the ice border, but not the maximum position held during the development of the Bloomington morainic system.

The moraines of southwestern Tippecanoe County do not continue with strength into Montgomery County. The outer one is traceable no farther than the Coal Creek valley in the north edge of the county. The second one, though easily traced to Sugar Creek near Crawfordsville, lacks the strength displayed nearer the Wabash Valley. Its knolls are not closely aggregated, but inclose nearly plane tracts that occupy about half the surface. Few of them exceed 25 feet and most of them are but 10 to 15 feet high. Between Sugar Creek and the Boone County line the knolls are so scattered that it is difficult to trace the border.

Boone and Clinton counties.—Boone County, though owing its high altitude to a very thick deposit of drift, does not present definite morainic ridges. By combining a series of bowldery strips, chains of gravelly knolls, and heads of peculiar troughlike valleys that may be lines of glacial drainage, a sort of rough outline for the ice border may be drawn through the southern portion of the county. The valleys referred to are along the headwaters of Eel River and seem to have been cut by large streams which headed very abruptly in these southern townships of Boone County, as if emerging from the ice sheet. Possibly they are to some extent subglacial, but in any case they are excavated so deeply that the present streams are filling instead of eroding them. The bluffs range from 20 to 50 feet in height and are in places bordered by chains of knolls that add much to the irregularity of the surface, some of them being 20 to 30 feet in height.

In the southeastern part of Boone County bowlders as well as knolls abound. Fishback and Eagle creeks run through belts of undulating drift which in places take on a morainic appearance, especially where the knolls are thickly strewn with bowlders. In contrast to these irregularities of the southern townships the central and northeastern parts of the county are remarkably smooth, there being wide areas in which there is scarcely a knoll.

Farther north, in Clinton County, an undulating surface continues that of southern Tippecanoe County and, like it, stands above a plain on the north. It is therefore probable that during the development of the Bloomington morainic system the ice receded from southern Boone northward into central Clinton County, a distance of about 25 miles, leaving only scattered knolls and short strips of bowlders in its retreat.

Hamilton County.—The undulating tract which traverses central Clinton County from west to east curves around to the south through southwestern Tipton County and runs southward through the western part of Hamilton County. In places, as in the vicinity of Sheridan east of Horton and southeastward from Westfield to White River, sharp knolls are closely aggregated and give a decidedly morainic appearance to the surface. But on the whole the surface is gently undulating or nearly plane.

Marion County.—This undulating topography continues down the west side of White River to Indianapolis and also appears on the east bluff immediately above the city. Some of the

sharpest knolls in the entire length of the morainic system are found in the vicinity, the most prominent one perhaps being Crown Hill, which stands on the east bluff near the northern edge of the city, rising about 125 feet above the gravel plain on its west side. The southeastern part of Marion County is nearly all undulating, but the sharp knolls are restricted to a narrow strip near the east bluff of White River, or rather at the eastern edge of a gravel plain 2 to 4 miles wide that leads down the valley. A single group of sharp knolls appears on the west bluff of the river just north of the south line of the county. The river from Indianapolis southward into northern Johnson County seems therefore to follow closely the outer edge of the morainic system.

Johnson County.—Near Glen Valley, at the south edge of Marion County, there is a ridge about a mile in length, 75 to 125 feet in height, and scarcely one-fourth mile in width. North of it about 2 miles, near Little Buck Creek, there are ridges 30 to 50 feet in height, and between Lick Creek and the city of Indianapolis there are others. In northwestern Johnson County along the south side of Pleasant Run a ridge 50 to 75 feet high and scarcely more than one-half mile in width is practically continuous for 4 miles. From its eastern end near Greenwood a less prominent but very bowldery morainic belt, composed of knolls and ridges 15 to 40 feet in height which show a tendency to an east-west trend, runs eastward for about 8 miles. A conspicuous ridge lies east of the pike south of Greenwood. A sag border or trough about 100 yards wide, standing but a few feet below the level of the bordering plain, runs along the south border of this belt for several miles in the vicinity of Greenwood, separating the moraine from the outer border plain. Possibly it was developed by border drainage, but quite as probably it was occupied by the ice during the development of the moraine and is a glacial fosse, the ice limit being on its south edge.

Hancock and western Henry counties.—The ridge in northern Johnson County, just discussed, is at the south border of a broad undulating tract 12 to 15 miles in width that leads from Marion County eastward across southern Hancock and northwestern Rush counties into Henry County, its northern limit being near the Cleveland, Cincinnati, Chicago & St. Louis Railway. The belt as a whole trends nearly west and east, but individual ridges have a northeast-southwest trend and these govern the course of small streams to a marked degree. The easternmost ridge or undulating belt lies along the west side of Sixmile Creek; a second belt lies west of Brandywine Creek; a third lies west of Sugar Creek below its bend. Few knolls in Hancock County exceed 20 feet and the majority fall below 10 feet in height. In southeastern Marion County there are several square miles bearing closely aggregated knolls 15 to 30 feet high, and winding ridges of irregular shape and height inclosing basins. Near Julietta, in the vicinity of the Cincinnati, Hamilton & Dayton Railway in southeastern Marion County, a few knolls rise 30 to 40 feet above the bordering districts.

In Henry County the undulating belt narrows from about 12 miles at the western edge to less than 3 miles in the vicinity of Mount Summit north of Newcastle. The knolls are somewhat scattered where the belt is broad but show definite ridging and close aggregation as it narrows. The moraine is very strong from a point near the meridian of Newcastle eastward into Ohio.

Immediately west of Newcastle about 4 miles is the north end of a sharp gravel ridge which forms the front of the moraine for 5 miles, terminating on the south at the village of Greensboro. It lies along the east side of Duck Creek and rises abruptly about 50 feet above the swampy plain through which the creek flows and about 20 feet above the plain on the east. In form and constitution it is strikingly like an esker, but its position with respect to the moraine is not the usual one. Instead of leading into the moraine from the inner border district it appears to have been developed along the edge of the ice sheet. Between it and the gravel plain along East White (Blue) River is a till plain of remarkable smoothness about 2 miles in width, but on its western side the topography is morainic.

Delaware and northern Henry counties.—In southeastern Delaware County the larger knolls are chiefly along depressions or lowlands occupied by the small creeks which lead northward

to White River. In many places they lie in north-south chains or nearly at right angles to the trend of the moraine.

A little farther west, in southern Delaware and northern Henry counties, a complex system of winding ridges incloses basins and marshy tracts, in which the East White River gravel plain begins. The marshy tracts drain southward into a single large channel in the northern part of Henry County.

From the head of this channel to Mount Summit a system of ridges and knolls rises abruptly 75 to 100 feet above bordering swampy tracts. Its sharpest ridges lie back about 2 miles from the edge of the gravel plain, the intervening space being gently undulating and thickly strewn with bowlders.

Randolph and Wayne counties.—In southern Randolph and northern Wayne counties, Ind., the moraine covers an uneven surface of uplands and lowlands, the lowlands being occupied by the headwater branches of Whitewater River. The ice sheet apparently overhung valleys which had been cut in the drift and deposited its knolls on the slopes and bottoms. Oscillation may have resulted in an overriding of the heads of the lines of glacial drainage. The knolls of this region are closely aggregated and thickly strewn with bowlders, but very few of them reach a height exceeding 30 feet.

STRUCTURE OF THE DRIFT.

COMPOSITION.

In most of the region traversed by the Bloomington morainic system the superficial portion of the drift is a yellow till bearing a few scattered gravel knolls, but in a district comprising several square miles in southeastern Delaware and northeastern Henry counties, about the head of the East White gravel plain (Collett's glacial river), knolls, ridges, and intervening marshy tracts alike are composed largely of gravel. Gravelly knolls and narrow strips of flat-surfaced gravel also occur along certain valleys where the bordering uplands are till. Throughout this region the percentage of gravel is generally larger in the steep knolls than it is in the low swells, the latter as a rule being composed of till. It is not rare to find hills from which all the gravel has been removed for commercial use, leaving only till. In some hills the gravel is confined to one side; in others it forms the body of the hill, the superficial portion being till; and in still others it is in pockets on the surface, the body of the hill being till. Throughout the morainic belt in Indiana the gravel is conveniently distributed for use on the roads.

CONTACT OF WISCONSIN AND PRE-WISCONSIN DRIFT.

The occurrence of buried soil found in wells of southwestern Boone County (records of which follow) is of service in dividing the drift into earlier and later sheets, the portion above the buried soil being probably of Wisconsin age.[1]

Section of Shelly well, 4 miles north of Jamestown.

	Feet.
Soil and yellow clay, mixed with sand	12
Sand, yellow	2
Gravel, hard	4
Hardpan gravel	4
Sand, white	6
Sand and clay, bluish	18
Muck or loam, black, with branches of trees and other vegetable matter	12
Clay, blue	4
Sand, gravel, etc., gray	26
	88

[1] These records are from the Fifteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1886, pp. 166–173.

Section of Emert well, 2½ miles north of Jamestown.

	Feet.
Soil	2
Clay, yellow, and sand	28
Quicksand	1½
Clay, blue	29
Muck, black; leaves, twigs and branches of trees	3
Sand and clay	12
Shale, siliceous, "soapstone"	160
	235½

Section of gas well 3 miles southeast of Elizaville.

	Feet.
Soil and yellow clay	18
Quicksand	3
Clay, blue	20
Sand, white (gas)	11
Clay, blue	6
Swamp muck, leaves, twigs, etc	7
Clay, blue	19
	84

Section of Vandeveer well, 6 miles south of Lebanon.

	Feet.
Soil	2
Clay, yellow	18
Clay, blue	45
Swamp muck, leaves, twigs, etc	10
Clay, blue	25
Sandstone	9
	109

There are indications that in parts of central Indiana scarcely 20 feet of drift were deposited during the Wisconsin invasion. In western Tipton and southern Clinton counties a buried soil about 20 feet below the surface seems to represent the land surface previous to the Wisconsin invasion. In southern Madison County a black mucky soil, carrying pieces of wood large enough to be called logs, underlies the till at 15 to 40 feet.

Many deep borings made in the search for natural gas disclose the great thickness of the drift and the position of the preglacial valleys. The records of some of these borings are sufficiently definite to bring out the contrast between the soft, easily penetrated Wisconsin drift and the hard, partly cemented, underlying supposed Illinoian or pre-Wisconsin drift. As no natural exposures reach the pre-Wisconsin drift information concerning it is obtainable only from these borings. The writer, however, examined a set of samples of drift taken from a gas boring at Lebanon which was of much service in interpreting records in the neighboring districts, and he has little doubt that the change from soft to hard till marks the passage from Wisconsin to pre-Wisconsin drift.

Section of drift in Lebanon, Ind., gas well.

	Feet.
Soil, black	2
Till, yellow (Wisconsin)	9
Till, blue, becoming gray toward bottom	15
Sand with water	1½
Till, ash-colored, soft and sticky (probably Wisconsin)	77
Gravel	8
Till, pale, ash-colored, hard and dry (probably Illinoian)	53
Till, dark ash or gray, with some sand interbedded (probably Illinoian, if not older)	176
	342½

The following section of a well on Washington Street in Lebanon, as reported by Gorby and Lee,[1] shows how complex the bedding in the Wisconsin drift may be. It appears not to have reached the pre-Wisconsin.

[1] Fifteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1886, pp. 170.

Section of well on Washington Street, Lebanon, Ind.

	Feet.
Soil	7
Sand, yellow	1
Clay, yellow	3
Sand, bluish, and clay	1
Sand	4
Clay, blue	3
Sand and gravel	4
Clay, blue	2
Clay, gray	3
Hardpan (indurated clay)	4
Clay, blue, laminated	14
Clay, gray	3
Sand and clay	10
Clay, blue	23
Gravel, coarse	1
Clay, blue	25
	108

At Zionsville, in the southeast part of Boone County, a gas boring entered yellow till under blue till at a depth of 88 feet, and the transit may mark the passage from the Wisconsin to the Illinoian till, though its low altitude rather favors the view that it is in the midst of pre-Wisconsin drift. The well is in the valley of Eagle Creek and may start at a level as low as the base of the Wisconsin. The following is its section:

Section of drift in gas boring at Zionsville, Ind.

	Feet.
Sand and gravel, with a little clay	30
Gravel, coarse	8
Till, blue	±50
Till, yellow and blue, in alternate beds; containing pieces of wood	±60
Bowlder, large	7
Clay, yellow	10
	165

At Sheridan, in western Hamilton County, a bed of red clay near the base of the drift may prove to be a preglacial residuary clay of exceptional thickness. The driller, Mr. Holleran, of Noblesville, noted in it decomposed pieces of white rock such as appear in residuary clay in some limestone regions. The well was largely through blue till for 150 feet, through sand and gravel for 40 feet more, and through 43 feet of red clay resting on limestone at 233 feet.

Another well, on the Mandlin farm, 3 miles west of Newcastle, shows 243 feet of reddish clay underlying about 60 feet of ordinary yellow and blue till. Rock was struck at 303 feet. All the Wisconsin drift may be included in this 60 feet of till.

THICKNESS OF THE DRIFT.

Few well records indicate or suggest the depth of the Wisconsin drift along the belt, but a number throw light either on its thickness or its structure. These are noted below in order from the Ohio-Indiana line westward.

Randolph County.—At Lynn two gas-well borings, each beginning at an altitude about the same as the railroad crossing (1,162 feet), penetrate one 117 feet and the other 124 feet of drift. In each the upper 50 feet is till and the remainder mostly assorted material.

In the eastern part of Winchester a gas boring passed, principally through till, to 160 feet, at which depth a bowlder was struck and the boring abandoned. West of Winchester 1½ miles a gas well penetrated 333 feet of drift, some of which is till and a large part sand. Several gas wells in the vicinity of Winchester strike rock at depths of 80 to 100 feet after penetrating more till than assorted material. A water well at Fountain Park Cemetery, in Winchester,

penetrated 210 feet of drift and did not reach the rock. Another at Frank Moorman's residence in the southern part of the village did not reach rock at a depth of 205 feet.

At Windsor, in western Randolph County, a gas well penetrated 107 feet of drift, mainly sand and gravel.

At Losantville, in southwestern Randolph County, a gas well passed through 240 feet of drift, mainly till but containing some sand and gravel in its upper portion.

Henry County.—At Mooreland, Henry County, a gas well penetrated 150 feet of drift, mainly till but containing beds of gravel at about 90 feet.

In a gas boring at Mount Summit 235 feet of drift was found, mainly assorted material.

At Springport a gas well near the level of the depot, on comparatively low ground, penetrated 70 feet of drift, much of which is assorted material.

At Middletown, in Fall Creek valley, a gas-well boring penetrated 160 feet of drift, which includes some till but is mainly assorted material; a strong flow of water comes from 83 feet. Another gas well on the uplands in the north part of Middletown, about 15 feet above the level of the railway station, penetrated 203 feet of drift. Like the one in the valley it has some till, but the drift is principally sand and gravel.

A gas well 1½ miles north of Mechanicsburg, Henry County, has over 200 feet of drift, largely till. A log thought by the well driller to be sycamore was struck at about 200 feet.

At Cadiz a gas well penetrated 421 feet of drift and entered shale of Ordovician age, there being no limestone of Silurian age.

At Kennard a gas well penetrated 227 feet of alternate beds of till and assorted material in nearly equal amounts.

In the vicinity of Greensboro rock is struck at 100 feet or less.

Rock is exposed in East White River 3 miles or more above and again a short distance below Knightstown. At Knightstown several gas wells penetrate from 64 to 100 feet or more of drift. They begin on a gravel plain along the river, 50 to 75 feet above the river bed, and penetrate 20 to 25 feet of gravel, below which blue till continues to the bottom of the drift. Blue till outcrops along the river bluffs below the gravel in the vicinity of Knightstown.

Hancock County.—Several gas borings have been made in the vicinity of Greenfield. The least thickness of drift reported is 150 feet, in the valley of Brandywine Creek; the greatest thickness is about 200 feet in a well which starts at 889 feet, about the same altitude as the railway station. Nearly all the wells passed through surface till about 30 feet thick, below which are alternate beds of till and assorted material. The assorted material apparently exceeds the till in quantity.

At New Palestine the thickness of the drift is 285 feet, but the character of the material was not ascertained.

At McCordsville, in northwestern Hancock County, a gas well penetrated 186 feet of drift, mainly till.

Marion County.—In northeastern Marion County, at Oakland, a gas well penetrated 231½ feet of drift, of which the following section is reported. The well is about 35 feet below the level of the depot, 810 feet.

Section of drift in Oakland gas well.

	Feet.
Till, yellow and blue	56½
Sand and gravel	50
Till, blue, with but little sand or gravel	125
	231½

Northwest of Oakland, along Fall Creek, several gas wells penetrated partly till and partly assorted material, as follows:

Altitude and thickness of drift in wells.

	Altitude.	Drift.
FALL CREEK VALLEY NEAR OAKLAND.	*Feet.*	*Feet.*
Johnson well	770	155
Kimberlin well	777	156
Rambo well	777	177
Manseur well	770	228
Wolf well	784	160
UPLANDS NEAR FALL CREEK.		
Near Lawrence	885	188
Brightwood well	804	190
Smart well	827	190
Speese well	827	141
Irvington gas well	820	130
Cumberland	838	230

Opposite these wells the drift is much thinner north of Fall Creek than it is south of the stream, not only because the drift surface is lower but because the rock surface is higher. In a well at Cumberland about 50 feet of yellow and blue till overlies alternate beds of assorted material and till.

The Indianapolis gas companies have bored many wells in Marion County along White River above Broad Ripple, and have found thicknesses of drift ranging from 50 to 90 feet. The least thickness found is at Broad Ripple; the greatest is west of Allisonville. About a mile east of Allisonville on the uplands, at an altitude of 75 feet or more above White River, a well penetrated only 78 feet of drift.

In Indianapolis, on the gravel plain along White River, 35 to 60 feet or more of assorted material overlies a blue till. Several wells[1] ranging in depth from 67 to 88 feet show a gravel stratum 38 to 61 feet thick. Several gas borings in the city, some on the gravel plain and some on the till tract east of the gravel plain, show drift varying in thickness from 80 to 118 feet. It is thinnest on the till tract, though the altitude there is 20 feet or more greater than on the gravel plain, and is thickest in the valley of Fall Creek near North Indianapolis, on low bottom land about 20 feet below the Union Depot (688 feet above sea level), where it is 118 feet thick.

Along White River, between Broad Ripple and Indianapolis, are some fine exposures of blue till. The bluffs are in places 60 feet high and show scarcely any gravel outcrops. Though lines of deposition or lamination have been noted[2] in this blue till, it is very pebbly, and may not differ greatly in origin from tills in which no lamination is observed.

Hamilton County.—A gas well at Carmel, in Hamilton County, in a valley near the depot, penetrated 96 feet of drift. A half mile east of this well, on ground some 30 feet higher, a well passed through 62 feet of till, beneath which was sand to the bottom of the well at 135 feet.

One of the gas wells in Westfield struck rock at 196 feet, the other at 220 feet; in both the drift is mainly a blue till. A gas-yielding well in a valley about 3 miles southeast of Westfield penetrated 95 feet of drift, of which the upper 20 feet is till and the remainder sand and gravel.

Gas wells at Jolietville and Eagletown, in western Hamilton County, each passed through about 200 feet of drift, mainly till. In the Eagletown well a bed of quicksand 20 feet thick near the bottom of the drift caused much difficulty in completing the boring.

Boone County.—At a sawmill in Royalton, in the Fishback Valley, some 60 feet below the level of the upland, a well about 100 feet deep penetrated mainly blue till, the only gravel encountered being a 5-foot bed about 25 feet from the surface.

A gas well 4½ miles northeast from Lebanon penetrated 285 feet of drift. Its section is said to differ from that of the gas well in Lebanon (p. 99) in containing less of the hard and dry ash-colored clay near the bottom.

[1] Twelfth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1883, pp. 92-93. [2] Idem, p. 93.

A boring 5 miles west of Lebanon, on Claiborn Cain's farm, found gas in the drift at 73 to 78 feet. It was continued largely through blue clay to a depth of 243 feet without reaching rock.

The following sections and data in the vicinity of Thorntown were contributed by J. A. Ball,[1] who states that a heavy deposit of dry gravel, the total thickness of which is not known, lies about 1½ miles west of Thorntown. On the farm of Mr. Charles Moffit a well was dug through 4 feet of soil and 40 feet of gravel, when it was discontinued without finding water. At other places in the same locality gravel is known to be of considerable depth.

Section of Mills well, 1 mile east of Thorntown.

	Feet.
Soil and yellow clay	25
Quicksand	3
Clay, blue	80
	108

Section of Harris well, 1 mile south of Thorntown.

	Feet.
Soil and yellow clay	19
Quicksand	4
Clay, blue	103
Gravel, cemented	6
	132

Section of Woody well, 3½ miles west of Thorntown.

	Feet.
Soil and yellow clay	18
Sand, fine, white	55
Clay, blue	71
Limestone	3
	147

Section of well near Union Church, 3 miles east of Thorntown.

	Feet.
Soil and yellow clay	27
Quicksand	9
Clay, blue	75
	111

Section of Witt & Klizer's well at Thorntown mill.

[Given by J. A. Ball, who superintended the boring.]

	Feet.
Soil	2
Clay, yellow	19
Quicksand	4
Clay, blue	125
Shale, siliceous ("soapstone")	193
	343

[Re-collected by engineer at the mill.]

Soil	2
Clay, yellow	13
Gravel	3
Clay, blue	82
Cedar tree.	
Clay, blue	37
"Soapstone"	60
Limestone, gray	136
	333

Section of Dukes & Wetherald's wells, 3 miles north of Thorntown.

[The wells are on opposite sides of the road.]

	Feet.
Soil and yellow clay	18
Quicksand	12
Clay, blue	153½
Sandstone, red	3½
	187

The present writer obtained records of gas borings at Thorntown which show much less drift than that at the mill. One in the valley of Prairie Creek in the east part of the village penetrated about 40 feet of drift, mainly sand and gravel; the other, on the uplands in the south part of the village at an altitude 35 feet or more above the well in the creek valley, penetrated about 75 feet of drift, also mainly sand and gravel. In both a limestone occurs which is wanting in the well at the mill.

Tipton County.—At Kempton, in western Tipton County, the gas borings, although all starting at an altitude of about 925 feet, show drift ranging in thickness from 243 to 306 feet, as follows: Near depot, 306 feet; 500 yards east, 257 feet; 700 yards east, 243 feet; about a mile southwest, 260 feet.

Section of drift in well 500 yards east of Kempton station.

	Feet.
Soil and yellow till	10
Sand and till in alternate layers each a few feet in thickness, the till mainly blue	165
Gravel	65
Clay, sandy, very hard	17
	257

[1] Fifteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1886, p. 173.

In the well 200 yards farther east the driller recognized three series of beds, each consisting of till, sand, and gravel, in the order named. The till in the lower series is harder and drier than that in the middle and upper. The drillers were unable to give the thickness of the individual beds.

Section of drift series in well at Kempton.

	Feet.
Upper series of till, sand, and gravel	75
Middle series of till, sand, and gravel	85
Lower series of till, sand, and gravel	83
	243

Section of drift in well by Kempton depot.

	Feet.
Till	100
Sand	75
Gravel, fine	75
Clay, blue, with bowlders	56
	306

The drift in the well a mile southwest of Kempton is said by the secretary of the Frankfort Gas Co. to be mainly blue till, but no accurate record was kept.

Clinton County.—At Scircleville, in Clinton County, a gas boring, altitude 930 feet, penetrated 296 feet of drift. The upper 150 feet is mainly till. Below this thin beds of sand alternate with till for about 30 feet, beneath which is 115 feet of cemented gravel.

At Mr. Lee's, 4 miles east of Frankfort, a gas well at an altitude of about 900 feet penetrated about 300 feet of drift. A boring south of Frankfort, altitude about 860 feet, did not reach the bottom of the drift at 297 feet. Several wells along Prairie Creek in Frankfort flow from a bed of sand beneath a heavy bed of blue till, at a depth of about 80 feet. A well in the northeast part of Frankfort, altitude about 850 feet, has the following section:

Section of drift in well at Frankfort.

	Feet.
Till, yellow and blue	30
Quicksand	10–15
Clay, hard, and gravel, interbedded	25–30
Gravel and sand, with thin beds of clay	197
Clay, blue, pebbly	13
	285

Tippecanoe County.—At Dayton, in Tippecanoe County, a boring in the valley of South Wildcat Creek, the surface of which is 50 feet or more below the level of the railway station, or about 600 feet above sea level, penetrated 160 feet of drift. The rock surface stands more than 200 feet higher at Buck Creek station, in the northern part of the county, for rock is struck there about 20 feet below the level of the depot, or 653 feet above sea level.

At the courthouse in Lafayette, in the valley of Wabash River, an artesian well penetrated 170 feet of drift, the rock surface being but 380 feet above sea level. William McKay, who superintended the boring, gives the following section:

Section of artesian well at Lafayette, Ind.

	Ft.	in.
Clay	3	
Clay and gravel	9	6
Gravel and pebbles	1	6
Gravel, fine, and sand	13	
Quicksand	1	
Gravel, clay, and pebbles	2	6
Clay, dark gray	72	
Sand and gravel	4	
Clay and pebbles	1	3
Sand and gravel	7	3
Clay		6
Sand and gravel	3	
Clay and pebbles	6	6
Gravel, pebbles, and bowlders	45	
	170	

Benton County.—At Templeton, in Benton County, altitude 700 feet, W. J. Templeton made a boring many years ago to 300 feet without reaching the bottom of the drift; no flow of water was obtained.

A gas boring on Joseph Atkinson's farm, about 3 miles southwest of Oxford, penetrated 410 feet of drift to a coal-measure shale lying about 320 feet above sea level. The drift is mainly blue till but contained beds of sand and gravel about 10 feet thick.

A boring for coal made many years ago by W. J. and L. Templeton and others on the Templeton farm 6 or 7 miles southwest of Oxford, in sec. 32, T. 24 N., R. 8 W., passed entirely through the drift. W. J. Templeton gave from memory the following section:[1]

Section of well on Templeton farm.

	Feet.
Soil	2
Clay, yellow	10
Clay, blue	25
Gas; burned for weeks.	
Clay, blue	90
Gravel, cemented	25
Clay, yellow, and gravel	110
Shale, black (?)	10
Clay and sand	100
Limestone, gray	90
Shale and limestone	75
	537

The black shale may not really be a shale, for the clay and sand which underlie it appear to be drift, which may extend to the gray limestone at 372 feet. As the altitude at this boring is probably not far from 750 feet, the top of the gray limestone lies at about 380 feet.

At Talbot, about 5 miles west from the coal boring, altitude 764 feet, a well was sunk to 310 feet without reaching the bottom of the drift. J. B. McKinney, of Fowler, who made the boring, stated that the greater part of the drift is a dry sand, of yellowish color near the top but assuming a bluish color in the lower portions. The only clay bed he recollected was a few feet thick and about 60 feet from the surface.

Mr. McKinney has made several other deep well borings in Benton County which have not reached the bottom of the drift. One at Mr. Bennett's on the ridge passing west from Parish Grove in the northeast part of sec. 33, T. 25 N., R. 9 W., is 264 feet deep, including about 25 feet of till at the surface, overlying mainly a dry yellowish sand or sandy till. On the same ridge, at Lawrence Bros.', sec. 4, T. 24 N., R. 9 W., the section of a well 240 feet deep is similar.

A well at the post office in Fowler, 160 feet deep, encountered no rock; it is in sandy till or dry sand from the top nearly to the bottom, where water-bearing sand was struck. A natural-gas boring one-fourth mile north of the depot and at about the same altitude (823 feet) struck rock at a depth of 158 feet, mainly water-bearing sand. West of Fowler along Mud Creek wells penetrate 50 to 75 feet of dry sand or sandy reddish till before obtaining a good supply of water. Wells drilled by Mr. McKinney about 5 miles east of Fowler reach rock at comparatively slight depths. One in the northwest part of sec. 15, T. 25 N., R. 7 W., at Wayne Johnson's, struck rock at 65 feet; the drift is entirely till, much of it yellowish. Another well in the northwest part of sec. 10 of the same township struck rock at 72 feet; the drift is till except about 5 feet of gravel at the bottom.

A well 185 feet deep, on the farm of Samuel Davis just east of Boswell, struck no rock.

In Ambia borings have been made to 100 feet, striking rock.

[1] See also Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1887, p. 33.

BOWLDERS.

In eastern Indiana the Bloomington morainic system is in places very thickly strewn with bowlders. A well-defined belt enters from Ohio into northeastern Wayne County and for a few miles follows nearly the line of Wayne and Randolph counties, and then passes north of west into northeastern Henry and southeastern Delaware counties. It swings abruptly southward near Mount Summit at the head of the East White gravel plain and follows the moraine about to Cadiz in western Henry County, where it ceases to be well defined. The width of the strip over which the bowlders are sufficiently numerous to seriously obstruct land cultivation is only about a mile; but from this thickest part they grow gradually fewer toward the north for several miles. In western Randolph County they abound over the whole district between White River and the southeast corner of the county. They are thicker along the southern margin of the belt in Henry County near the head of Stony Creek and of East White (Blue) River than they are farther north.

In Hancock County some small districts carry bowlders as abundantly as any part of the larger belts. One of the most conspicuous areas is found in the level portion of the county between the two branches of the Cleveland, Cincinnati, Chicago & St. Louis Railway. Bowlders occur in great abundance and large size in secs. 21, 22, 27, and 28, Vernon Township, about 2 miles south of Fortville, and are numerous along the east side of Sugar Creek southeast of Eden in secs. 25, 30, and 36, Green Township. In other parts of the county and in northern Shelby County they are not conspicuous.

In northern Johnson and southern Marion counties bowlders cover the moraine and the plain north of it so thickly that farms of 160 acres ordinarily have several thousand on their surface. They are especially numerous near Rocklane, where some fields have a hundred or more to the acre. McCaslin [1] says:

> The bowlders are everywhere thickly studded in a solid matrix of clay. Near Rocklane a multitude of unusually large ones were seen, sometimes a hundred of them in an area of a few acres, many of them 10 to 15 feet in length and weighing many tons. On the farm of W. F. Kimuck, in sec. 36, Clark Township, one was measured showing the following dimensions: Length over top, 18 feet 1 inch; circumference, 41 feet 10 inches; height above ground, 5 feet. Near this monster were a number of immense proportions. It was noticeable that there was a striking similarity in the bowlders of this ridge. They were mainly a coarse gray granite, appearing as though they came from the same locality, as doubtless they did.

In southern Marion County the bowlders are more numerous on the plain immediately northeast and east of the moraine than on the sharp ridges of the moraine itself. They are very numerous between Glen Valley and Southport and also north of Southport. In Indianapolis they are less numerous than at Southport though still abundant except on the gravel plain. At Crown Hill and northward along the east side of White River they are very abundant. They are less numerous for 2 or 3 miles west of White River than they are east of it or than they are for 2 or 3 miles east of Eagle Creek in northwestern Marion County.

In Boone County bowlders are numerous in clusters and in narrow strips a mile or so in length but do not form a well-defined belt. They are not rare, however, along the probable ice margin. Taken as a whole they seem to occupy a southeast-northwest tract 5 to 10 miles wide, which connects the more concentrated belt of Marion County with that in Montgomery County. They are rather numerous over the whole northwest fourth of Boone County, but are rare over the southwest fourth. They are abundant in the central and southeastern parts, but are rare in the northeastern part of the county. Unusual numbers were observed in the following places: In the extreme southeast section of the county; in the vicinity of Holmes station; along the Lebanon and Elizabeth pike from Lebanon northeast for about 4 miles; about a mile south of Pike Crossing; about 2 miles east of Thorntown in secs. 31 and 6, Washington Township; north of Sugar Creek, in secs. 15, 16, 22, 27, and 26, Sugar Creek Township, the southeast end being just north of Thorntown; near Dover along Muskrat Creek. The Linden-Darlington belt appears a few miles east of Crawfordsville and leads northwest to the Wabash Valley.

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[1] Thirteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1883, pp. 123-124.

Probably the best-defined belts of western Indiana, though not associated with so strong a moraine as that of eastern Indiana, represent transitory positions of the ice margin. As already indicated the bowlder belts north of Wabash River in western Indiana cross the ridges of the Bloomington system at various angles so as to show plainly that they can not represent precisely the same ice margin that the ridges represent.

INNER BORDER.

SLOPES.

In north-central Indiana a tract of about 4,000 square miles, extending from the Bloomington morainic system northeastward to the Mississinawa morainic system and northward to Wabash River, is without strong or well-defined moraines, though it has small tracts where the surface is undulatory and a few places where bowlders are numerous. In general its surface is plane and its drift is much thinner than on the belt south of it. This tract shows a westward descent of 200 to 250 feet in 45 miles, dropping from 1,100 feet at the Ohio-Indiana State line to 850 to 900 feet on the meridian of Anderson. For 20 miles west from the Anderson meridian, in Madison, Hamilton, and Tipton counties, the altitude is remarkably uniform. The southern part of the tract then rises westward into the great drift belt in western Hamilton and southwestern Tipton counties, ascending 60 to 100 feet in 8 or 10 miles. Farther north the tract very gradually descends to the northwest toward the Wabash Valley, its altitude at the border of that valley being about 700 feet. From the great drift belt in eastern Indiana northward about to White River the descent is abrupt, being 120 feet in 10 miles from Bloomingsport to Winchester, 150 feet in 9 miles from ridges near Luray to Muncie, and 140 feet in 14 miles from Warrington to Anderson.

ESKERS.

RAUB ESKER AND ESKER TROUGH.

A depression about one-half mile in width and 20 to 30 feet in depth leads from the edge of the low plain at Raub southwestward up Little Wea Creek past the Linden-Darlington bowlder belt. It narrows sharply on entering the moraine outside the bowlder belt, and is traceable across the moraine to Shawnee Creek only through narrow sags scarcely 100 yards wide winding among the knolls. Evidence to support the view that a lake had been held between the retreating ice border and this divide was not discovered. What little channeling has been done at the divide was probably accomplished by streams issuing from the ice sheet when it stood at or near the edge of the moraine. The broad depression along Little Wea Creek is occupied by an esker which terminates at the Linden-Darlington bowlder belt, and it seems to have been developed in advance of the esker, as is usual in esker troughs.

The esker heads on the low plain 1½ miles northeast of Raub, in the south part of sec. 29, T. 22 N., R. 4 W., and is developed as a small but practically continuous ridge 8 to 10 feet high and 50 to 60 yards wide as far as Raub, where it strikes the south bluff of the channel or depression above described just east of the railroad station and is deflected northwestward about 150 yards but there turns back to its southwestward course and leads up the channel. It is interrupted in places for the first mile beyond Raub, but from there on it is nearly continuous for about 2 miles to sec. 10, T. 21 N., R. 5 W., where it attains its greatest height of about 40 feet. It enters the Linden-Darlington bowlder belt in sec. 10, and has only a weak development in the form of low knolls in this and adjoining sections on the south and west. One of these knolls near the southwest end of the esker is cut by the wagon road on line of secs. 9 and 10 and shows some till with a poorly assorted sandy gravel. The esker so far as opened elsewhere appears to be composed of gravel of medium coarseness and much better assortment than in this exposure. In Indiana and neighboring States the writer has found a few other occurrences of till with the assorted material at the morainal end of an esker. No esker fan or sand plain exists at the southwest end of the esker unless it be below the bed of the channel in which the esker lies. The esker seems to be on a slight upgrade from Raub to its southwest terminus, the altitude of

its base being less than 700 feet at its northeast end, very nearly 700 feet at Raub, and 725 feet or more at its southwest terminus.

SHORT ESKERS IN SOUTHERN TIPPECANOE COUNTY.

Some of the ridges in secs. 31 and 32, T. 21 N., R. 4 W., in southern Tippecanoe County, resemble short eskers, but have around them irregular knolls such as characterize moraines. The trend of the esker-like ridges is northwest and southeast, but that of the morainic knolls and ridges is variable, some running nearly at right angles to the eskers and others being nearly parallel to them. Knolls in secs. 32 and 36 stand 30 to 40 feet above the general level. The esker ridges are lower; one, which is continuous for about 1½ miles, extending from the south part of sec. 29 southwestward to Wea Creek in the eastern part of sec. 31, is 10 to 30 feet high and nowhere exceeds one-eighth mile and in most places does not exceed 75 to 100 yards in width. It does not lie in a well-defined channel or trough, though it terminates at the southwest in a boggy tract depressed a few feet below the general level of the bordering land. North of this ridge, in the northwest part of sec. 32, a smaller gravel ridge about one-fourth mile in length, 150 yards in width, and 10 to 15 feet in height, runs parallel with it only a short space away. In the south part of the SE. ¼ sec. 30 is another ridge of similar length and trend. Terminating as these ridges do at the bowlder belt in the midst of the morainic knolls, they appear to bear a close relationship to the moraine, but being composed of assorted material and trending parallel with the ice flow and not at a right angle to it, they are thought to be the product of subglacial drainage.

HAZELRIGG ESKER AND ESKER TROUGH.

Among the esker-like ridges one worthy of note lies in the south part of sec. 23 and the north part of sec. 26, T. 19 N., R. 3 W., in Montgomery County. Though scarcely a half mile in length and 100 yards in width, it rises abruptly to heights ranging from 15 to 40 feet. It is curved, with its concavity toward the northwest. It stands in the valley of a tributary of Muskrat Creek, which here occupies a portion of a shallow channel of glacial or subglacial drainage that heads farther northeast in western Boone County in the valley of Sugar Creek in sec. 23, T. 20 N., R. 2 W., about 2 miles west of Thornton. In Boone County, and also in eastern Montgomery County, knolls and low ridges of gravel occur at short intervals along this channel, which is apparently the product of a subglacial stream, for its course is toward, and its southern terminus is in, the moraine. The channel is about one-half mile in width and is still 15 to 20 feet in depth, though partly filled with peat and muck.

ANDERSON ESKER AND CHANNEL.

Course and altitude of the channel.—A remarkable abandoned channel, consisting of a marshy valley partly filled with peaty deposits and occupied in part by an esker, passes from southern Grant County (where it drains into Mississinawa River) southward to the East White gravel plain in northern Shelby County, a distance of about 60 miles. After passing over the divide between Mississinawa River and Pipe Creek near Summitville it leads down to Pipe Creek at Alexandria, then over the divide between Pipe Creek and White River and across White River at Anderson. Continuing southward in disregard of the present system of drainage, it crosses Fall Creek east of Pendleton and Sugar Creek at Eden (in Hancock County), and finally enters the Brandywine Valley at the point where the creek turns south a few miles north of Greenfield. It may be nearer the truth to say that Brandywine Creek enters the channel, for the latter is probably older than the creek and it is much larger than the valley of the creek above the junction. The channel is followed by Brandywine Creek to the gravel plain east of Fairland. Throughout this whole distance the channel has abrupt bluffs as if it had been cut down rapidly by a stream. It is, as a rule, but one-eighth to one-fourth mile wide, but in the portion between White River and Fall Creek its width is nearly a mile. In this wide portion it contains an esker which follows it from Anderson southward for 4 miles. It is bordered throughout nearly its entire length north of the junction with Brandywine Creek by a smooth till plain, but along

Brandywine Creek the topography is of a subdued swell and sag type. Its depression below the bordering uplands for most of its length is only 15 to 20 feet, but this does not represent its original depth, for it is deeply filled with peaty material which caused much trouble in the early construction of roads across it.

The range in the altitude of this channel is not great, and the divides crossed by it are of remarkably similar heights, as shown in the table below. Beyond the last divide in central Hancock County the altitude gradually decreases down the channel.

Range in altitude along abandoned channel in Grant, Madison, Hancock, and Shelby counties, Ind.

	Feet.
Summit on divide between Mississinawa River and Pipe Creek near Grant-Madison county line (canal survey, 1835)	882
Pipe Creek valley at Alexandria (Lake Erie & Western Railroad survey)	850
Summit on divide 3 miles south of Alexandria (barometric)	890
White River at Anderson, 25 to 30 feet above present bed (canal survey)	850
Summit south of Anderson (canal survey)	889
Fall Creek valley (Cleveland, Cincinnati, Chicago & St. Louis Railway survey)	845
Summit between Sugar Creek and Brandywine Creek (Cleveland, Cincinnati, Chicago & St. Louis Railway survey)	885
Near Greenfield (Pittsburgh, Cincinnati, Chicago & St. Louis Railway survey)	835

Origin.—Two hypotheses as to the origin of such a channel may be considered. By the first it is assumed that the summits noted above mark successive positions of the ice margin and that the portion of the channel between each summit and the stream south of it was occupied by a stream which flowed no farther south but turned down the intersecting valley. For example, the broad channel leading from the summit near White River, just south of Anderson, southward to Fall Creek would be the product of a later stream than the channel leading from the Fall Creek and Sugar Creek divide southward to Sugar Creek, and still later than the one from the Sugar Creek and Brandywine Creek divide to Brandywine Creek, but earlier than the channel north of White River leading from the divide south of Pipe Creek to White River. Under this hypothesis the ice may be conceived to have had either of two quite different positions relative to such portions of the channel as lie between a given divide and stream. At the time of the formation of each channel the ice may have had its margin at the southern end of the channel, in which case the channel would have been formed by a subglacial stream; or it may have had its margin at the summit, in which case the channel would have been formed or at least enlarged outside of the ice sheet by waters that were not confined by ice walls. Certain phenomena, however, seem to be incongruous with this latter conception; for instance, the Anderson esker, which occupies the channel and rises in places higher than the bluffs of the channel and yet was evidently formed in it after the channel had been excavated, seems to call for the presence of the ice sheet and the confinement of ice walls; and again, certain gravel deposits that fringe the channel and rise in places somewhat above the level of the bordering till tracts seem to call for a stream that followed approximately the course of the channel. This second conception, therefore, seems untenable at least for that part of the channel, and the conception of a subglacial origin for the channel seems more nearly in accord with the features along the valley.

The second hypothesis as to the origin of the channel starts with the assumption that the channel was formed from end to end by a single subglacial stream that started some 60 miles back from the margin of the ice and flowed to the margin, rising and falling with the rise and fall of the surface of the ground beneath the ice sheet but ever keeping straight onward because the superincumbent ice sheet prevented escape to either side. The hydrostatic pressure is assumed to have been strong enough to have carried the stream over the low summits which lay in its course. The fact that the channel is not disjointed between the sections, as assumed in the first hypothesis, and the further fact that it rises from the valleys southward to the divides, maintaining similar sharply defined bluffs up the slope, across, and down the slope of each divide, lend much strength to this hypothesis. Possibly there was an initial opening of the

channel well toward its north end, which, during brief halts like those at Fall Creek and White River, was utilized and in places expanded by streams issuing from the margin. In this manner, perhaps, may be explained the greater size of the part of the channel between White River and Fall Creek as compared with that south of Fall Creek.

Material in the channel.—Borings have been made in or near the borders of the channel at Fairmount, Summitville, Alexandria, Anderson, Huntsville, and Greenfield. Rock rises nearly to the surface at Fairmount near the line of Grant and Madison counties, being struck at 5 to 30 feet. At Summitville a boring for gas a few rods east from the channel passed through 15 feet of till and a great depth of gravel, evidently older than the channel, and struck rock at 111 feet. At Alexandria the rock is struck at slight depth in the valley of Pipe Creek and on the uplands, so there is probably but little drift beneath the abandoned channel in the vicinity of this town. At Huntsville a gas boring near the east side of the channel penetrates 20 feet of drift, mainly muck and boggy material.

The esker.—The esker in this channel extends from the White River bluffs in the north part of Anderson nearly south-southeast for about 4½ miles to the north line of Fall Creek Township in sec. 2, T. 18 N., R. 7 E. It has a height of 10 to 40 feet and a breadth of 50 to 150 yards and is nearly continuous, being broken only by small gaps and by a few places where it is very faint. In the southwest part of Anderson, near the corners of secs. 13, 14, 23, and 24, it is most prominent. It is narrow to within one-half mile of its north end, where it expands into a level-topped ridge 100 to 200 yards wide, on which the courthouse and main business portion of the city is built. It stands 30 feet or more above the channel, which here lies almost wholly on the west. It is separated on the east from the uplands by a slight sag 8 to 10 feet or less below the level-topped portion and but 50 to 75 yards in width. The esker at its north end has very nearly the same altitude as the uplands east of the sag, 880 feet above sea level; near its southern end it rises in places 20 feet or more above the bordering uplands, the channel in which it lies being depressed about 15 feet below the upland plain.

So far as opened this esker is composed mainly of fine gravel or gravelly sand. Several wells along it in Anderson have penetrated gravel to 40 or 50 feet; and one well, at the residence of Charles Henderson, to 91 feet, a level slightly below that of White River. The lower part of this gravel may, however, be older than the esker. This abandoned channel has much gravel beneath it wherever borings have penetrated it, but as the gravel extends in places outside the limits of the channel it is likely to be in part older.

The structure and thickness of the drift are exceedingly variable in the vicinity of Anderson. On the esker at Charles Henderson's residence gravel was penetrated to 91 feet without reaching rock. At the strawboard factory in the abandoned channel only 16 feet of drift was found. At the glass works southwest of Anderson in the abandoned channel a boring passed through 194 feet of drift, all sand and gravel. In Killbuck Creek valley north of White River a gas boring encountered 50 feet of gravel and sand. On the north bluff of White River near the crossing of the Pittsburgh, Cincinnati, Chicago & St. Louis and Cleveland, Cincinnati, Chicago & St. Louis railways a gas well passed through 191 feet of drift, of which a large part was till. A water well west of the crossing of the same railways in Anderson penetrated much till and did not reach the bottom of the drift at a depth of 104 feet. On the uplands west of the abandoned channel about 2½ miles southwest from the courthouse a water well penetrated 160 feet of drift, mainly till with thin beds of fine sand, without striking rock. These records indicate that the altitude of the rock surface beneath the abandoned channel changes fully 160 feet within a short distance.

A fine gravel constituting the bulk of the esker is exposed in a pit near its south end. The bedding is discordant in the lower part but is nearly horizontal in the upper. A capping of brown clayey gravel ranges from a few inches to several feet in thickness. The cobblestones, which are numerous in the fine gravel, and the smaller pebbles are nearly all of limestone and are apparently of the same kind of rock as the underlying strata, Silurian limestone. A collection of pebbles an inch or less in diameter, gathered without attempt at selection, were classified as follows:

Pebbles in esker near Anderson, Ind.

	Feet.
Limestone, blue	36
Limestone, buff	54
Quartz	4
Chert; probably from the limestone	14
Crystalline rocks; mainly granite	22
	130

These pebbles are subangular to well rounded, especially the limestones. The granites were not much rounded. No striated pebbles were observed.

RIDGES AND BOWLDER BELTS.

GENERAL RELATIONS.

Short morainic ridges and bowldery strips in the vicinity of the Wabash Valley in Tippecanoe and bordering counties may be correlatives of the inner part of the Bloomington morainic system of the Illinois lobe, for at the west they are separated but little from the ridges of that system. One weak moraine and bowlder belt passes through the city of Lafayette, and other weak moraines or undulating strips lie between it and the Linden-Darlington bowlder belt.

HIGHGAP RIDGE.

The southernmost definite ridge of this district is known to the residents as Highgap Ridge. It leads eastward from the Wabash Valley at West Point to Taylor station on the Chicago, Indianapolis & Louisville Railway, and, after an interruption of about 2 miles at the valley of Big Wea and Little Wea creeks, continues eastward to Culver, beyond which it appears to be merged with the Stony Prairie belt discussed below. West from the Wabash it becomes blended with the innermost strong moraine of the Bloomington system and takes a northwestward course to Pine village. The most prominent portion of its independent course is that between West Point and Taylor, where a stretch of sharp knolls and ridges 15 to 40 feet in height, inclosing basins holding ponds, occupies a belt about one-half mile in width. The portion east of Wea Creek has a swell and sag topography with few basins. Its north edge was cut into sharply by what appears to be a line of border drainage connected with the next later belt.

In the portion between West Point and Taylor it is very gravelly, being little else than a chain of kames, but in the remaining portion till apparently predominates over gravel and sand. The surface is in places thickly set with small stones, but bowlders or large stones are not conspicuous.

STONY PRAIRIE BOWLDER BELT.

A belt named from Stony Prairie, in western Clinton County, is not only exceptionally bowldery but carries numerous small drift hummocks 10 or 12 feet high that put it in contrast with smooth tracts on its borders. Bowlders are present in great numbers in secs. 15, 16, 9, 10, 3, and 4, Washington Township, and in secs. 33 and 34, Madison Township, in a belt about one-half mile wide, but are not rare east of this belt for 2 miles or more.

From the south end of the Stony Prairie bowlder belt Twelvemile Prairie runs south of east to Kirklin. Its surface is not hummocky nor thickly strewn with bowlders but is sufficiently ridged to present a well-defined crest and may mark the continuation of the ice margin in that direction. It is, however, too vague to be interpreted with certainty.

From the north end of Stony Prairie a weak belt of small knolls and shallow basins leads westward to the north side of South Wildcat Creek near Mulberry, recrossing the creek south of Dayton. Between the two crossings and from the second crossing westward a shallow channel, apparently formed by ice border drainage, follows the southern edge of the undulating belt closely to the Wabash Valley about 4 miles south of Lafayette. This belt fades out in the vicinity of the Wabash Valley and is not continued west of the river, unless it is merged with a later belt that crosses the river in the city of Lafayette.

The general width of this weak undulating belt is scarcely a mile, and few of the knolls in it exceed 20 feet in height. Near its inner border, however, a mile west of Dayton, a sharp knoll 60 feet high and a similar knoll east of the river form conspicuous landmarks. Basins are not rare along its southern edge, and some stand in the supposed border drainage channel, suggesting that the work in the channel was completed before the ice had entirely melted away. The width of the drainage channel averages about a mile. The fact that the stream cut strongly into the north slope of the part of Highgap Ridge bordering it is thought to indicate that the ice border stood close by the ridge at the opening of this drainage, and that the channel broadened with the melting back of the ice.

FOWLER-LAFAYETTE BOWLDER BELT.

In the north part of Lafayette the bowlder belt crosses Wabash River in a course a few degrees north of west and south of east. On the west side of the Wabash it occupies the high land between the West Lafayette reservoir and the Soldiers' Home and, covering a belt 1½ to 2 miles wide, runs westward past Montmorency and just south of Otterbien to the corners of Benton and Warren counties at the west side of Tippecanoe County. Thence it continues slightly north of west past Templeton to Oxford, where it turns northward to Fowler and connects with an extensive bowldery area.

East from Lafayette it lies mainly on the south side of Wildcat Creek to the mouth of South Fork, though it has a small extension on the north side in secs. 12 and 13, T. 23 N., R. 4 W. East of South Fork it lies on both sides of Middle Fork in the southeast part of T. 23 N., R. 3 W., its north border being within one-half mile north of Monitor and Petit post offices. There is some uncertainty as to its continuation in Clinton County, there being only scattered knolls in the direct line of continuation and no apparent grounds for continuing the ice border in an indirect course.

The width of this bowldery belt is generally between 1 and 2 miles, and it is on the whole better defined than the Stony Prairie belt. Like the latter it covers numerous small hummocks. The drift is largely till of rather clayey texture. The border drainage is not so definite as that along the Stony Prairie belt, and it is probable that the Wabash Valley and Indian Creek valley each served as lines of drainage. On Indian Creek a gravelly terrace is thought to mark such a line. On the Wabash gravel terraces are more conspicuous below Lafayette than immediately above it, and an interbedding of outwash gravel and till at the south edge of Lafayette seems to mark the passage from glacial to fluvioglacial deposits. The gravel plain standing a few feet above the broad Wea Plain along its southern edge may prove to be the outwash at the time when Stony Prairie was forming, but the connection with that belt is not clear enough for satisfactory correlation.

MINOR UNDULATING STRIPS.

Four or five miles north of the Lafayette bowlder belt and running nearly parallel with it in western Tippecanoe and eastern Benton County a tract of undulating land standing slightly higher than the plane tracts north and south of it constitutes throughout much of its length a water parting. Its eastern end is in northwestern Tippecanoe County near Octagon, whence it passes northwestward across the southwest corner of White County and into southeastern Benton County for about 2 miles and dies out in a plain. The swells along this belt from Octagon northwestward are 10 to 20 feet high, but few of them are steep, a rise of 20 feet generally requiring fully one-eighth mile of slope. There is scarcely any level land in the belt. In the vicinity of Octagon a tendency to ridging in an east-west direction was noted.

The Octagon undulating tract is bordered by a sand ridge 5 to 15 feet high and 100 to 300 yards wide, composed of fine yellow sand, which sets in about 5 miles west of Brookston in southern White County and leads southwestward for 10 miles across the northwestern part of Tippecanoe County into southeastern Benton County. Were the ridge of gravel instead of sand it would seem best explained as an esker, but careful search failed to bring to light any pebbly material in it. Were the bordering material sand instead of clayey till the ridge might

be ascribed to the wind. But there is almost no sand on the bordering districts and little if any evidence of lake occupancy of the region after the retreat of the ice. The origin of the ridge, therefore, remains uncertain. Very few points within several miles are higher than the ridge, which stands on a prominent part of the upland 700 feet or more above sea level.

Another undulatory strip 1½ miles wide, carrying basins as well as low swells, follows Fall Creek from Middletown to Pendleton in Madison County, but does not appear to extend west of Pendleton.

Another gently undulating strip about a mile wide follows the north side of White River from Anderson westward to the Hamilton County line, where it crosses to the south side of the valley and continues between White River and Stony Creek, apparently terminating at the bend of White River north of Noblesville. Bowlders are somewhat more numerous on it than on border plains, but few of the swells exceed 10 feet in height, and no connection was established between it and any well-defined moraine.

Along North Wildcat Creek from Burlington to Cutler and south from there to the vicinity of Sedalia in northern Clinton County there is an isolated belt of a dozen or more square miles in which knolls 20 to 40 feet high occur.

Along the east bluff of the Wabash in Carroll County a belt a mile or more in width displays a tendency to ridging parallel with the river. The most prominent ridges lie west of Rockfield in secs. 1 and 2, T. 25 N., and sec. 36, T. 26 N., R. 2 W.; they stand 20 to 30 feet above the low ground between them and slightly less above the plain to the southeast. About 3 miles northeast of Delphi, near the corners of secs. 14, 15, 22, and 23, a group of gravel knolls rise rather sharply 12 to 15 feet above interspersed basins. Together they cover less than a square mile. All around them the surface is very gently undulating.

What is perhaps the best-defined and longest undulating strip in the district consists of scattered knolls distributed over a strip 1 to 5 miles in width, leading from Muncie northwestward to Peru. Its south border in western Delaware County leads westward near the line of the Lake Erie & Western Railroad into Alexandria. After crossing a swampy channel west of Alexandria it turns northwestward and leads past Rigdon and Point Isabel into Howard County, where for a few miles it forms the divide between Wildcat Creek and the headwaters of Pipe and Deer creeks. It runs into Miami County between the north and south forks of Deer Creek past the village of Wawpecong, comes to North Deer Creek at Miami village, and thence runs north to Pipe Creek and Bunker Hill. It then follows Pipe Creek valley northwestward to the Wabash at the line of Miami and Cass counties about 5 miles west of Peru. Few places in this strip bear knolls exceeding 15 feet in height, and less than one-fourth of the surface is more undulatory than the bordering plains. Only in Miami County do bowlders abound and they are about as numerous west of the undulatory strip as they are along it.

STRUCTURE OF THE INNER BORDER.

COMPOSITION.

General features.—Till constitutes the greater part and especially the surface portion of the drift of the intermorainic tract or inner border. What little gravel there is on the uplands is in the sharp knolls or in small patches in the till plain, there being no extensive gravel plains. Along the valleys of the principal streams considerable gravel and some gravel knolls and ridges occur. There is also, as indicated above, gravel in the Anderson esker and in the abandoned channel in which the esker lies.

Wells in Boone, Clinton, and Madison counties (see p. 99) pass at depths ranging from 15 to 60 feet through a black mucky soil which may indicate the top of the deposit at the preceding ice invasion. A soil is struck in some localities at exceptional depth—for example, at 103 feet in the "Brobst" gas well in southeastern Howard County.

Of many well sections and estimates of drift thickness collected, the following have been selected:

Delaware County.—At Muncie the thickness of drift in the several gas borings ranges from nothing to 100 feet, though the altitude of the surface does not vary more than 25 feet.

At Daleville wells penetrate 8 to 15 feet of yellow till and obtain water at slight depth in sand and gravel. A gas well penetrated 12 to 15 feet of yellow till. The remainder of the drift is sand and gravel. Rock was entered at 85 feet.

Madison County.—At Markleville a gas boring penetrated 147 feet of gray till containing thin beds of sand and gravel. A piece of wood was struck at about 140 feet. The altitude of this well by gravel-road survey is 100 feet above Pendleton, or 945 feet above the sea.

In Elwood gas well No. 1 penetrated 108 feet of drift, mainly blue till. Gas well No. 2, near Duck Creek, at an altitude 10 or 12 feet lower than No. 1, penetrated 65 feet of drift, mainly till, except for about 12 feet of sand at the bottom. Gas well No. 3, one-half mile east of the village on ground as elevated as No. 1, penetrated only 40 feet of drift.

Hamilton County.—At Clarksville, P. P. Whitesall has a gas well which penetrated 16 feet of drift, and his neighbor William Coverdale has another at a similar altitude that penetrated 82 feet of drift. At Mr. Sohl's, about a mile west of Clarksville, two wells penetrate each only 6 feet of drift.

Two miles east of Noblesville, at the "Granger wells," the drift is 80 feet thick, of which the greater part is gravel. Near Noblesville nearly all the gas wells and water wells penetrate much gravel, the only marked exception noted being a well west of White River in which till constituted the bulk of the 98 feet of drift. Many of the wells, however, in which the greater part of the drift is sand and gravel, contain a thin bed of surface till. The thickness of the drift varies considerably, a well two blocks north of the courthouse in Noblesville having 136 feet, another one-half mile north in White River valley at an altitude about 30 feet lower having only 33 feet, and a third 1½ miles north of the courthouse on the upper gravel terrace along the river passing through 176 feet. In this last well assorted material persisted to 40 feet or less of the bottom, at which depth a red ocherous clay overlying the limestone was entered.

At Cicero the following sections of drift in gas wells were reported by William Neal: Well No. 1 has 161 feet of drift, of which the upper 15 feet is till and the remainder more sand and gravel than till. Well No. 2, on ground 8 or 10 feet lower than No. 1, has 141 feet of drift, which includes more till than No. 1 but has a large component of sand and gravel. Well No. 3, a mile south of Cicero, at an altitude not perceptibly different from that of No. 1, has 270 feet of drift, including a bed of till about 20 feet thick at the surface; below this for 175 feet the drift is chiefly sand and gravel, with thin beds of clay; the lowest part (about 60 feet) is a red clay, apparently like that at Noblesville, in which no pebbles were noticed.

At Arcadia records of two gas wells show 146 and 130 feet of drift, nearly all till, mainly blue. Thin beds of sand and gravel were passed through.

At Atlanta, near the line of Hamilton and Tipton counties, a gas well penetrated 320 feet of drift, consisting of yellow and blue till to about 80 feet and of sand and gravel on to the bottom.

Tipton County.—In southeastern Tipton County at Mr. Hobbs's residence in sec. 36, T. 21 N., R. 5 E., a well struck rock at 73 feet. The following is the section of drift:

Section of drift in Hobbs well in southeastern Tipton County.

	Feet.
Till, yellow	15
Till, blue, putty like; few pebbles	50
Sandy material, yellow with crust of gravel	8
	73

In the level plain along the Lake Erie & Western Railroad east of Hobbs station there is a small tract of surface gravel which is used for ballast on the road. In this gravel bed many large angular blocks of limestone are embedded. Near Hobbs station are two gas wells. One in sec. 1, T. 21 N., R. 5 E., penetrates the following beds of drift:

Section of drift in gas well at Hobbs station.

	Feet.
Till, yellow and blue	38
Gravel	5
Till, blue	45
Gravel	15
	103

Other sections in this county are given below.

Section of drift in well in sec. 10, T. 21 N., R. 5 E.

	Feet.
Till, yellow	10
Gravel	20
Till, blue	80
Gravel	20
	130

Drift in wells at Tipton.

[Altitude about 870 feet.]

	Feet.
Well No. 1, in north part of village	139
Well No. 2, one-half mile west of No. 1	152
Well No. 3, in east part of village	200

A gas well at Windfall, in northeastern Tipton County, penetrated 72 feet of drift, mainly blue till, but including thin beds of sand and gravel.

Howard County.—At the Barrett gas well, in southeastern Howard County, in sec. 21, T. 23 N., R. 5 E., is the following section of drift:

Section of drift in Barrett well.

	Feet.
Till, yellow	10
Gravel, loose	40
Gravel, cemented	48
	98

In the Probst well, sec. 7, T. 23 N., R. 5 E., the well driller reports striking beneath the till, at 103 feet, a bed of dirt and leaves, underlain by sand and gravel extending to limestone at 115 feet.

At Tampico two gas borings show a difference of 28 feet in the thickness of drift, the thicker being in the well on the lower ground. In each the upper portion, to a depth of 25 feet, is till and the remainder sand and gravel with thin beds of till.

At Sharpsville a gas well penetrated 70 feet of drift, mainly till.

A gas well 4 miles east of Russiaville, in southern Howard County, penetrated 165 feet of drift. A boring in Russiaville penetrated 153 feet, of which the upper 60 feet is till and the remainder largely sand and gravel.

In several wells in Kokomo and vicinity drift is absent or ranges up to 88 feet in thickness.

At Greentown, 8 miles east of Kokomo, most wells obtain water at 20 to 25 feet in gravel below till. A lower vein of water is struck at 35 to 45 feet. Gas borings show the drift to be about 85 feet in thickness.

At Fairfield a village well struck rock at 47 feet, another well one-fourth mile northeast on slightly lower ground at 72 feet, and a third one-half mile north of the village on ground about 20 feet lower than the first well at 26 feet. In all these wells the drift is mainly till. Most of the wells draw from beneath the first sheet of till at 20 or 30 feet. A well near the railway station has 47 feet of drift, of which the upper 18 or 20 feet is till and the remainder gravel. Gas borings show the drift to range from 25 up to fully 75 feet.

Grant County.—In southwestern Grant County the drift is thin and consists of a few feet of till underlain in many places by a bed of water-bearing sand or gravel. Gas borings show the following thicknesses: At Switzer, 28 feet; Swayze, 22 feet; Simms, 45 feet; Point Isabel, 22 feet; Fairmount, 5 to 35 feet.

Miami County.—At Xenia (Converse post office) dug wells end at 10 to 20 feet in gravel beneath a sheet of till. The drift ranges from 25 up to 100 feet or more in thickness. In the

southeastern part of the county many wells penetrate 50 to 70 feet of till, though shallower ones are common.

At Amboy the wells penetrate about 15 feet of till, beneath which a water-bearing gravel extends to rock at 35 to 50 feet.

At Bunker Hill a sheet of till 25 to 40 feet thick is generally passed through before water-bearing sand or gravel is reached. In one gas well the drift is 68 feet, in another 84 feet; in each the lower half is largely sand and gravel. A boring east of Bunker Hill in sec. 21, T. 26 N., R. 5 E., at an altitude 175 feet above Wabash River at Peru, penetrated 160 feet of drift, of which 54 feet is till and the lower 6 feet gravel.

Cass County.—At Galveston, Cass County, on ground 20 feet lower than the railway station, or 775 feet above the sea, a gas boring penetrated 41 feet of drift. Rock outcrops along Deer Creek west of Galveston.

At Walton the drift is about 80 feet. At Logansport drift is lacking in the valley and is very thin for some distance to the south on the uplands.

Carroll County.—At Delphi also drift is lacking in the valley and is thin on the uplands to the east and south.

At Flora there is 136 feet of drift, mainly till. Several flowing wells near the creek differ in depth, some being but 12 feet and others 40 to 45 feet deep. In the deeper two water beds occur above and below beds of blue till. There is said to be a ferruginous crust above the water beds and the water is strongly chalybeate. The probable source and head of water is from the higher ground south and southeast of Flora.

Clinton County.—Two wells near Geetingsville, on a knoll at R. G. Young's, only 50 yards apart, show a marked difference in material:

Record of Young well No. 1.

	Feet.
Sandy and gravelly clay	12
Till, bluish-yellow	33
Gravel	6
Till, bluish-yellow	14
Sand	6
	71

Record of Young well No. 2.

	Feet.
Clay, sandy and gravelly	6
Sand	25
Gravel, coarse, at bottom	2
	33

Dr. Young has a well on a level tract in the village of Geetingsville 125 feet in depth which does not reach the bottom of the drift. The section was not obtained. At J. H. Brown's residence, one-half mile west of Geetingsville, is a gas-yielding well with the following section:

Record of Brown well.

	Feet.
Till, yellow and blue	68
Sand and vegetable material with gas; sand cemented in places	16
Sand, with thin clay beds	40
Gravel	2
	126

Several flowing wells have been obtained in a valley in sec. 19, T. 23 N., R. 13 E., at a depth of only 20 feet.

At Mr. Stevenson's, about 2 miles west of Sedalia, a well was driven through 80 feet of till. No sand was noted and no water obtained. Afterward a well was dug at the same spot, and water was obtained in a thin sand bed at 20 feet. This illustrates the fact that the reported section of a driven well is less reliable than that of a dug well or large excavation.

At the railway station in Mulberry a well was driven, mainly through blue till, to a depth of 220 feet without reaching rock.

Tippecanoe County.—From well sections given by Gorby in his report on Tippecanoe County [1] the following, which represent the deepest wells, are reproduced:

[1] Fifteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., 1886, pp. 87–95

Section of Kinney well, sec. 15, T. 22 N., R. 4 W., 2½ miles east of Culver.

	Feet.
Soil	2½
Clay, yellow	8
Clay, blue	40
Hardpan	3
Water at	53½

Section of well at schoolhouse No. 6, Wea Township, 3 miles southwest of Culver.

Soil	2
Clay, yellow	8
Sand and gravel	6
Clay, blue	41
Water at	57

Section of Hicks well at Battle Ground (on terrace of Wabash River).

Soil	3
Hardpan	3
Gravel and sand	73
	79

Section of Clue well at Battle Ground.

Soil and yellow clay	4
Gravel, coarse	25
Sand	30
Clay, blue	1
	60

Section of Thomas well, 3½ miles east of Battle Ground.

Soil and clay	4
Gravel and sand	20
Hardpan	20
Sand and gravel	25
Clay, gray	2
	71

Section of Hoyleman well, 4½ miles northeast of Battle Ground, in Moot Creek valley.

Soil and clay	6
Clay, hard, blue	54
No water at	60

Section of Peffley well, 1 mile northwest of Colburn.

	Feet.
Soil and clay	4
Clay, blue	40
Gravel, dry, coarse	20
No water at	64

Section of Livingston well, 2 miles west of Battle Ground.

Soil and yellow clay	30
Sand, fine, dry	20
Clay, blue	30
Gravel, cemented	2
Gravel, loose	13
Water at	95

Section of Bryant well, 3 miles west of Battle Ground.

Soil and yellow clay	4
Clay, blue	50
Sand, dry	20
Gravel, coarse	2
No water at	76

Section of Brown well at Buck Creek station.

Soil	2
Clay, yellow	3
Clay, blue	15
Sand, fine, yellow	30
	50

Section of Cole well, 1½ miles west of Buck Creek station.

Soil and yellow clay	6
Gravel and sand	49
Clay, blue	5
	60

Section of Stanfield well, 2 miles north of Buck Creek station.

Soil and clay	4
Fine sand	45
Gravel, coarse	12
Gravel, fine, with bowlders at bottom	4
Water at	65

Data concerning deep wells at Dayton and Lafayette are presented in the discussion of the Bloomington morainic system. In the northwestern part of Tippecanoe County there are deeper wells than any reported by Gorby, but the writer was unable to obtain reliable records of them. One on the Van Alla estate in the east part of sec. 18, T. 24 N., R. 5 W., 126 feet deep, struck no rock, nor did one 176 feet deep on a farm 2 miles northeast of Otterbein in sec. 26, T. 24 N., R. 6 W.

BOWLDERS WITHIN THE INNER BORDER.

Bowlders are not numerous except in very small patches on the great intermorainic tract, and no system in their distribution was detected by which an ice margin could be marked out. The bowlders are mainly crystalline rocks, more than half being granite and the bulk of the remainder basic eruptives. A few red jaspery conglomerates from north of Georgian Bay were noted.

In the Wabash Valley at Logansport bowlders are exceedingly numerous, numbering where thickest 1,000 or more per acre. They also abound at intervals below Logansport for several

miles. These bowlders are probably a residue left where the drift has been cut away by the river.

STRIÆ IN THE INNER BORDER.

Striæ have been observed at five localities within the boundaries of the intermorainic tract. Exposures of rock strata are few and there is little opportunity for observation.

In a few places in a quarry south of and near White River about a mile below Anderson a flinty layer upon which striæ appear caps a shale that forms the greater part of the surface rock. The striæ bear from due south to S. 10° W. (magnetic).

Striæ were observed upon ledges in the north part of Free's quarry on the north side of a small stream in the southwest part of Alexandria, where the surface rock is a thick-bedded blue limestone which dips very gently west (about 1 foot in 150 feet). The surface is planed and on it shallow grooves one-fourth inch or less in breadth bear S. 39° W. (magnetic). The striæ near Anderson are in harmony with the trend of the esker and its trough, but those at Alexandria are not.

Striæ are found at the quarries south of Kokomo, on a small tributary of Wildcat Creek and just east of the Pittsburgh, Cincinnati, Chicago & St. Louis Railway. The rock here is a thin-bedded blue limestone, and the marks appear over the whole of the uncovered surface, comprising an area of several square rods. Most of them are fine lines, only 1 to 4 inches in length, the majority of which bear S. 50° to 70° W., but a few scattered ones bear from S. 20° E. to S. 80° W. The great difference is perhaps due to a changing series of ice currents, the locality being directly in front of the great curve in the drift belt, where the north-south trend in Hamilton and Tipton counties changes to east-west trend in Clinton County. Currents of ice in Howard County might pass southward against the western limb of the White River portion of the great drift belt or southwestward against the eastern limb of the Wabash River portion.

At the Davis bridge on Eel River northeast of Logansport the rocky bed of the river displays glacial groovings which bear S. 58° W. and some of which are several yards in length. The largest are 2 inches or more in width and one-third inch in depth. At the western end some of the grooves terminate abruptly at flinty places in the rock. Tapering projections in the lee of flinty prominences evidently owe their preservation to protection against the westward-moving ice. To this feature Chamberlin has applied the name "knob and trail."[1]

Glacial grooves and striæ were observed within the city limits of Logansport on the north bank of Eel River just below the upper dam, on a rocky ledge a few feet above the level of the river, where nearly all of a magnificent series bear S. 14° E. (magnetic). All the grooves have this bearing, but some of the striæ or fine lines bear more nearly south, the most southerly being S. 5° E. A careful search was made for evidence on the surface that would be decisive concerning the direction of ice movement, for it seems not unlikely that the moraine north of the river might have been formed in part by a lobe spreading northward, but nothing satisfactory was discovered for there are no prominent flinty knobs such as occur in the exposure in Eel River. Some light scratches which cross the grooves with a bearing S. 70° W., or in about the direction of the flow of Eel River, look in places much like glacial striæ, but they may have been formed by river ice. They appear only on the prominent parts of the rock surface and are very light and but a few inches in length.

GLACIAL DRAINAGE.

OUTER BORDER.

WHITEWATER RIVER BASIN.

East and West Whitewater rivers and some of their principal tributaries in Wayne County bear gravel plains which show that they were occupied by streams that flowed southward from the margin of the ice sheet while it was forming the moraines of northern Wayne and southern Randolph counties. These gravel plains constitute the terraces of the Whitewater and may

[1] Seventh Ann. Rept. U. S. Geol. Survey, 1888, p. 246.

be traced to an Ohio River terrace that stands approximately 100 feet above the bed of the river at the place where it is joined by the Whitewater gravel plain. The streams at the north ends are incised but little in the gravel plains, and they therefore descend about 100 feet more than the glacial streams in reaching the Ohio. Before the Whitewater had been filled with glacial gravel its bed was much lower than at present, as is well shown by borings at and near Brookville which enter rock 100 to 120 feet below the present stream. The valleys of the Whitewater system were probably filled in large part by earlier moraines than that under discussion, but it is quite likely that they received important additions of gravel and sand from it throughout their whole length.

EAST WHITE RIVER BASIN.

Westward a few miles from the Whitewater system is the head of the great gravel plain which is followed by East White (Blue) River. Its northern end is among the morainic ridges of southeastern Delaware County, whence a complex network of channels leads out to form the gravel plain. Prairie Creek has a channel one-fourth mile or less wide with a surface 20 feet or more below border tracts. The tributary channels west of it near the head of Bell and Fall creeks are shallower, but many of them have as great width. The valleys or marshy tracts west of New Burlington are also one-eighth to one-fourth mile wide, but they have no definite banks like the tributaries of Prairie Creek and probably have a greater filling with silt. The whole of the Delaware County portion of these channels and the portions within 2 or 3 miles south of the Henry-Delaware county line were apparently either extended northward on the withdrawal of the ice or were formed beneath the ice. Where East White (Blue) River enters this channel it emerges from the moraine and from this point southward has a much greater size than any of the channels formed within the moraine, being nearly one-half mile wide and 40 to 60 feet deep. This greater size does not seem attributable to the accession of the modern stream, but was probably produced by glacial drainage. Throughout Henry, Rush, and Hancock counties the channel is cut deeply into the till tract, but a small part of its bluffs being less than 50 feet and most of them being 60 to 80 feet higher than the broad plain in which the river flows. There is a terrace along this channel, but much of it was removed apparently by the glacial stream, for the channel which emerges from the moraine and which was abandoned with the cessation of glacial floods has a bed which traced southward forms the lower plain along the small stream that now occupies it. The terraces are in all probability the remnants of a gravel-filled channel which was filled by outwash either from an earlier moraine or from the early part of this moraine. The waters that escaped from the margin of the ice as the morainic system approached completion removed a portion of the gravel fillings from the northern part of the channel. In northern Shelby County the terrace descends more rapidly than the lower plain, so that it becomes merged in or buried beneath the later-formed valley drift. The glacial river channel gradually widens from north to south, being one-half mile wide at its emergence from the moraine, a mile or more at the line of Henry and Rush counties, and fully 1½ miles at the line of Hancock and Shelby counties. In Shelby County its width is still greater, but its depth is less, the bordering uplands standing only 15 to 20 feet above the gravel plain. In this county the river has cut a channel in the gravel plain which is very small compared with the glacial flood plain. In southern Shelby County it has cut a valley 15 to 20 feet deep and about one-eighth mile wide in the broad gravel plain. The stream gradually deepens its valley southward, so that at Columbus in Bartholomew County its bed is 30 to 35 feet and its flood plain 25 feet or more below the gravel plain. Features in Shelby and Bartholomew counties have already been described (pp. 70, 77).

The thickness of the gravel in the gravel plain in Shelby County has been ascertained by Mr. David Louden, a well driller residing at Shelbyville, to be 20 to 25 feet at most places and to exceed 40 feet at few. The amount of excavation is, therefore, a channel 40 to 50 feet deep, and this channel has been more than half filled with gravel.

In the upper portion of the East White (Blue) River valley no accurate sections were obtained of wells in the middle of the valley. On the border of the plain at Carthage and

Knightstown, wells show 20 to 50 feet of gravel. In most places a heavy deposit of blue till underlies the gravel, but in some rock underlies the gravel. The wells in the valley near Newcastle penetrate about 400 feet of drift, of which only a few feet is surface gravel.

The Sugar Creek gravel plain, which heads in northeastern Johnson and western Shelby counties, appears to have been an outlet for glacial waters at the time the morainic system was forming.

WHITE RIVER BASIN.

The large gravel plain of White River does not head in the White River valley but in the Fall Creek valley, White River being confined in a comparatively narrow valley above Crown Hill in north Indianapolis. The valley of Fall Creek begins to expand near Millersville, about 5 miles above Indianapolis, and within 3 miles its width increases from one-fourth mile to 2½ miles and where it enters White River is fully 3 miles. Below Indianapolis this plain maintains a width of 2 to 4 miles as far as Martinsville, in Morgan County, beyond which it shortly becomes narrower in its passage through the resistant limestone formations.

Above Indianapolis the width of the White River valley is about one-half mile except at some of the bends of the stream, where it is a mile or more. The abrupt enlargement of the valley just above Indianapolis is near the line of the inner edge of the morainic system and seems explainable as the work of a great stream issuing from the ice border. This stream must have started under the ice sheet 3 or 4 miles above the moraine.

From Indianapolis southward to the Johnson County line the moraine is aproned on the west by a gravel plain with basins and other irregularities along the line of junction. That this gravel plain, which stands several feet above a broad terrace of White River, is the product of glacial waters and is not a valley deposit made by White River is shown not only by its close relationship to the moraine but also by its perceptible descent from the moraine riverward. The material appears also to be coarser next the moraine than nearer the river. The western portion of the plain has been removed by White River, but the eastern portion remains intact, with basins along its eastern edge about the morainic knolls. In this portion the excavations reveal comparatively little sand and a large amount of gravel, largely of limestone, like the pebbles of the till.

West of White River, between it and Eagle Creek, is a plain which in places has what appears to be outwash gravels from the moraine. The gravel, however, does not entirely cover the surface, for places were observed where unmodified till crops out at the surface of the plain.

WALNUT CREEK BASIN.

In eastern Hendricks and southern Boone counties the outer border district is a till plain, upon the most level parts of which silty clays nearly free from pebbles range in thickness from a few inches to several feet. It is in this district that channels appear which have already been mentioned as probable lines of glacial or subglacial drainage. The largest channel heads about 2 miles southwest of Lebanon and extends southwestward down one of the headwaters of Walnut Creek for 7 or 8 miles, having too little descent to give the stream a good current. The channel at the north end is about a mile wide, but within 2 miles it becomes narrowed to one-fourth mile and maintains this width downstream for many miles, to enlarge only with the increasing size of the creek. Near its head it is depressed only 10 to 15 feet below the general level of the bordering plain, but it here occupies a boggy tract which was no doubt deeper when first abandoned. Its bluffs are steep like the banks of a river. This channel is along the westernmost of the Boone County streams that unite to form Walnut Creek. Two other tributaries farther east are characterized by similar channels. The middle of the three passes just west of the village of Milledgeville, below which it is bordered by knolls that rise a few feet above the general upland level, suggesting that both the channel and the knolls may be the product of a subglacial stream.

SUGAR CREEK BASIN.

There is a plane-surfaced gravelly district immediately northeast of Crawfordsville whose relation to the moraine is not clear. It heads just outside a weak moraine which crosses Sugar Creek at Garfield, and may be, in part at least, the outwash from that moraine. The gravel continues westward along Sugar Creek valley past Crawfordsville, but has been terraced by Sugar Creek, the main terrace being about 20 feet below the uneroded tract east of the city.

WABASH RIVER BASIN.

The Wabash seems to have furnished a channel for vigorous discharge throughout the development of the Bloomington morainic system. The gravel plain just west of Williamsport heads in a recess in the outer member. The great Wea gravel plain of western Tippecanoe County, which is about 4 miles wide (including the valley of Wabash River cut in it) and 9 miles long, and which fills the interval between Lafayette and the west line of the county, seems to have been developed during the recession of the ice across the district it covers. Its highest and oldest part is a strip on its south side less than a mile wide and about 3 miles long, which lies about 650 feet above sea level or 150 feet above Wabash River just east of West Point. Its altitude is about 630 feet at the east end and falls to about 615 feet 6 miles to the west, opposite West Point. The material is a fine sandy gravel such as would be expected in a broad plain with a slope of only 15 feet in 6 miles.

INNER BORDER.

From the slope and altitude of the surface the southern tributaries of White River would be expected to run northward to that stream, but they do so only from near Muncie eastward. West of Muncie the streams south of White River run nearly parallel with it. Fall Creek, the largest tributary, flows westward down a slope more gradual than that to the north. Lick Creek, the main tributary of Fall Creek, runs west entirely across Madison County only 2 to 5 miles from Fall Creek and at markedly higher level. Farther south in northern Hancock County the headwater portion of Sugar Creek runs west for 10 miles and then turns south through a depression in the great drift belt. The westward course of these streams may not be difficult to explain, the ice sheet in its lingering withdrawal probably causing the development of streams along its front which persisted after the ice had melted off. No clearly defined moraines along the north side of these west-flowing streams demonstrate this relation to the ice sheet, but the halts may have been too brief for their development. The westward course of the headwater part of White River is not remarkable, for it is in the line of as rapid fall as could have been selected. In Howard, Clinton, Carroll, and Cass counties the prevailing course of drainage is westward down a slope a little more gradual than that northwestward and directly toward the Wabash Valley, and here also it seems probable that the streams were westward along the south edge of the retreating ice, though definite moraines are not present fully to demonstrate this relationship.

In general the west-flowing streams of this region have cut narrow valleys, which deepen toward their mouths and are bordered by abrupt bluffs that stand about at the level of their border plains, but the west-flowing part of White River presents an interesting exception in part of its course. The valley deepens in the usual manner from its headwaters westward to the vicinity of Anderson, where it reaches a depth of 70 or 80 feet. West from Anderson the bluffs become less abrupt and soon drop to 30 feet or less, though within a mile or two back from the stream an altitude of 75 to 100 feet above the river is reached. The slopes are undulatory and some of the swells appear to have been built up by the ice sheet rather than left as a result of drainage erosion. It seems probable that this part of the valley was left as a depression and was only partly filled by drift deposits of the Wisconsin invasion.

Some of the northern tributaries of White River, notably Killbuck Creek, Pipe Creek, and Duck Creek, have valleys with broad undulatory slopes similar to the part of White River valley west of Anderson. Well-defined knolls on the slopes are thought to have been formed

by the ice sheet, but the fact that these valleys lead west of south, or about in the direction of ice movement as shown by striæ, renders it somewhat improbable that the undulatory belts mark the trend of the ice margin.

Wildcat Creek west from Kokomo has a valley 40 to 70 feet deep, the depth increasing toward the west. The bluffs are about as high as the land north of the creek, but are lower than the land south of the creek, for the plain rises 10 to 15 feet to the mile from the bluffs southward to the crest of the great drift belt in southwestern Tipton and southern Clinton counties. As a result the tributaries from the south are long and the country they traverse is well drained, but on the north they are trivial and the greater part of the plain for 3 to 5 miles north of the creek in Howard County is poorly drained.

CHAPTER VII.

THE SAGINAW LOBE.

By Frank Leverett.

GENERAL RELATIONS.

The axes of movement of the Lake Michigan, Saginaw, and Huron-Erie lobes converge toward northwestern Indiana, the Lake Michigan movement having been southward in the general trend of the Lake Michigan basin, the Saginaw southwestward through and beyond Saginaw Bay, and the Huron-Erie westward through the Lake Erie basin into Indiana. As a result of the convergence a coalescence, more or less complete, was effected and was maintained until destroyed by a rapid recession of the Saginaw lobe from the district south of the Kankakee. This coalescence has thus far made it unnecessary to make more than a passing reference to the several ice lobes.

A study of the moraines of northern Indiana and southern Michigan (see Pls. VI and VII) has shown that the portion of the ice sheet which moved southwestward from the Saginaw basin into Indiana melted back and disappeared from northern Indiana while the Lake Michigan and Huron-Erie lobes still extended into that State. This perhaps is not surprising, for the path of the Saginaw lobe, especially the part beyond the immediate basin of Saginaw Bay, was across more elevated country than the paths of the bordering lobes. Its thickness must have been correspondingly less and its movement correspondingly weaker, and these differences would become more noticeable with the waning of glaciation and the decrease in the bulk of the ice sheet.

It is somewhat surprising to find that several strong moraines were formed by the Saginaw lobe as it melted back from the border of the Kankakee basin into southern Michigan. Yet this may not be inconsistent with its comparative weakness. The convergence of the three ice movements might, at the culminating part of the Wisconsin stage of glaciation, have caused an excessive loading with drift material in the part of the ice sheet which subsequently became differentiated into the Saginaw lobe. This excessive loading may indeed have been even more influential than the comparative thinness of the ice in bringing about weakness of movement. However this may be, the fact remains that moraines that seem referable to the Saginaw lobe appear at intervals of only a few miles all the way back from the eastern edge of the Kankakee basin across St. Joseph, Marshall, Kosciusko, Elkhart, Noble, and Lagrange counties, Ind., and Cass, St. Joseph, and Branch counties, Mich.

The great line of glacial drainage at the junction of the Lake Michigan and Saginaw lobes, now traversed by St. Joseph River and its tributaries in Kalamazoo, St. Joseph, and Cass counties, Mich., to South Bend, Ind., and beyond South Bend by the Kankakee basin, breaks the continuity of the moraines, and being in a reentrant angle, increases the difficulties of correlating the individual moraines of the two lobes. A peculiar bunching or increase in bulk of moraines on the southeast border of the glacial drainage plain seems to indicate that the influence of the Lake Michigan lobe was felt even on that side. Illustrations are found south of South Bend and Bristol, Ind., and White Pigeon, Mich. As a rule, however, the moraines on the southeast were formed by the Saginaw and those on the northwest by the Lake Michigan lobe.

As a result of the recession of the Saginaw lobe, that part of the ice field came to have a position at the head of a recess between the Lake Michigan and Huron-Erie ice lobes, and it seems almost a misnomer to speak of it as a lobe during this early part of its differentiation.

The name "shoulder" might be more appropriate. With further recession into Michigan, however, reentrant angles developed between it and the Lake Michigan lobe on the one hand, and between it and the Huron-Erie lobe on the other, and the application of the term "lobe" becomes fitting. For a time the southern part of the Huron basin and the Erie basin held but a single lobe, the Huron-Erie, which later separated into two lobes, the Huron and the Erie.

The differentiation just suggested is the simplest possible. The actual history may have been more complicated. The border of the lobes, for instance, may have readvanced instead of merely halting at the moraines formed during the recession; complications of this sort, however, are not as yet sufficiently worked out to justify presentation. In the ensuing discussion the reentrant district between the Saginaw and Michigan lobes will first be considered, and then the several moraines—Maxinkuckee, New Paris, Middlebury, Lagrange, Sturgis, and Tekonsha—formed during the withdrawal of the Saginaw part of the ice sheet northeastward into Michigan will be taken up.

REENTRANT DISTRICT.

NEBO-GILBOA RIDGE.

In 1859 attention was called to the Nebo-Gilboa ridge by Richard Owen,[1] who termed two of its prominent knolls Mount Nebo and Mount Gilboa. Notwithstanding the appellation "mount" to these knolls (neither much exceeds 50 feet in height) the ridge is one of the smallest moraines in the State, its width averaging scarcely one-fourth mile and its height about 25 feet.

Throughout Benton County, Ind., the Nebo-Gilboa ridge constitutes the divide between the Illinois and Wabash drainage basins, but in White County it passes into the basin of the Wabash. It has a length of fully 30 miles and fades out in a plain 3 miles northwest of Brookston, Ind. A bowldery strip just south of the eastern end of the ridge, and possibly a dependency of it, continues eastward past Brookston to the Tippecanoe Valley, and there connects somewhat loosely with the Chalmers kame belt. In its western half the ridge reaches a little above 800 feet above sea level, and Mount Nebo and Mount Gilboa probably reach 850 feet. In its eastern half it gradually descends to about 700 feet. Its surface is gently undulating and it shows a definite crest along nearly its entire length.

The wells on the ridge are mainly through clayey till. Considerable till was found in a well on Mount Nebo, though parts of the knoll are sandy. Mount Gilboa seems to be composed largely of sandy gravel. These two knolls are to be classed as kames. Along the ridge bowlders are common but are not more conspicuous than on parts of the bordering plain.

At the time Monograph XXXVIII was written a ridge in eastern Iroquois County, Ill., now believed to be a continuation of the Nebo-Gilboa ridge, was supposed to be older[2] because of its position west of the great bowlder belt that was thought to mark the limits of the later Wisconsin drift. The bowlder belt, however, more nearly coincides with the border of the Lake Michigan lobe in the reentrant angle between the Lake Michigan and Saginaw lobes than it does in its passage over the Bloomington morainic system to the south. The ridge west of the bowlder belt and reentrant angle is a moraine of the Lake Michigan lobe, and the Nebo-Gilboa ridge is thought to be a correlative moraine formed by ice farther east which later became differentiated into the Saginaw and Huron-Erie lobes. The village of Earl Park, Ind., stands near the place of intersection.

CHALMERS KAME BELT.

The Chalmers belt is best developed within 4 miles east, northeast, and southeast of the village of Chalmers, in White County, Ind., but its kames are scattered over the plain from Chalmers to Tippecanoe River and from near Monticello to the Wabash Valley southeast of Brookston and a few are east of Tippecanoe River near Monticello. The knolls are sharp and rather closely aggregated near Chalmers, but near the Tippecanoe are separated by flat tracts of considerable extent. The highest knolls rise 50 to 60 feet above the bordering plains, and

[1] Ann. Rept. Indiana Geol. Survey for 1859, 1860, p. 219.
[2] The Illinois glacial lobe: Mon. U. S. Geol. Survey, vol. 38, 1899, p. 258.

knolls 20 to 30 feet high are numerous. So far as can be determined by exposures in gullies these knolls are composed largely of fine sandy gravel with only local beds of cobble or coarse material. Bowlders are not so numerous as on the bordering plain.

When first examined by Chamberlin and the writer in 1886 and 1887 this kame belt was thought to have been formed on the western edge of the Erie ice lobe after the ice had withdrawn from the Iroquois basin. By means of bowldery strips and scattered knolls it can be connected toward the northeast with a strong moraine, also thought to be a product of the Erie lobe. The failure to find any definite continuation toward the south left the interpretation somewhat in doubt. The region was reexamined by the writer and by A. H. Purdue in 1895 in connection with other studies in that region and was visited again by the writer in 1902. The correlation can not be said to be fully settled yet, but it now seems probable that the kame belt was formed while the ice covered the territory west as well as east of it, and it may be a correlative of the Nebo-Gilboa ridge. This kame belt and the bowldery tracts that extend northeast from it across northwestern Carroll County are thought to mark the junction of ice movement from the Erie and Saginaw basins before distinct lobes appeared in the process of the melting away of the ice. The evolution of the lobes is brought out step by step in the discussion of later moraines.

The continuation of the border of the Erie lobe across the Wabash seems likely to be found in a strip of gently undulating land with numerous basins that leads from Delphi southeastward past Flora to Wildcat Creek at Cutler, where it develops locally into a rather pronounced moraine. It was formerly thought that the ice border may have taken a southward course from near the mouth of the Tippecanoe along a bowldery belt on the east side of Wabash River and thus made connection with the moraine and bowlder belt a few miles east of the city of Lafayette. Owing to the poor development of morainic features in the district east of the Wabash, the mapping and interpretations must necessarily be somewhat indefinite.

BOWLDERY AREAS.

Bowlder-strewn areas are common on till plains in southern Jasper and western White and Pulaski counties, as well as in the vicinity of the Chalmers kame belt. They are not so numerous on the till plain on the immediate border of Iroquois River. Considerable time was spent in mapping these bowlder belts by Chamberlin in 1886 and by Purdue and the writer in later years, it being thought that their distribution might throw light on the manner in which the ice disappeared from the region. But though belts of considerable length were found no system in their distribution was detected. They trend in various directions and are especially abundant where surface sand is thin or wanting; indeed, they fade out as sandy areas are approached. Throughout much of the district bowlders are numerous where the bedrock is within a few feet of the surface, but they are also present where the drift is thick. It seems doubtful, therefore, if high altitude of rock surface was of much importance in determining their lodgment. Their distribution was probably determined by somewhat indefinite conditions within or upon the ice sheet in its vanishing stage.

As is common in belts along moraines the bowlders differ in kind and size and degree of angularity. The majority are granite, but many are of other rock types, among which are a red jaspery conglomerate apparently derived from Huronian ledges north of Georgian Bay, and a greenish conglomerate containing granite pebbles. Few are representatives of local rock formations. Many are 2 feet or less in diameter and few exceed 4 feet. They range from well rounded to sharply angular, the rounding appearing to have been produced by weathering rather than by water action. The absence of striated or glacially planed surfaces on all but a few of the bowlders distinguishes them from rocks included in the drift, many of which show glacial planing and striation.

MARSEILLES MORAINIC SYSTEM.

COURSE AND CORRELATION.

In Monograph XXXVIII the Marseilles morainic system of the Illinois lobe was traced as far east as the village of St. Anne, Ill., a few miles southeast of Kankakee, and it was noted that its natural continuation lay eastward along a ridged belt and bowldery strip north of Iroquois River in Newton and Jasper counties, Ind., to which the name "Iroquois" moraine was applied. It was suggested that this "Iroquois" moraine is the result of two ice advances differing widely in date as well as in direction, one advance being from the north in the earlier Wisconsin substage, and the other from the south or southeast in the later Wisconsin substage. Much of the relief along the moraine was ascribed to the earlier advance, and only the bowlders and the low knolls on its surface were considered to be the product of the later one. As an alternative it was suggested that the moraine might stand in the line of an interlobate spur formed at the junction of the Illinois and Erie-Saginaw lobes, and that the numerous bowlders are a result of this interlobate condition. The date of the formation of this interlobate spur was placed in the later Wisconsin substage.

It now seems necessary to suggest another interpretation, namely, that the "Iroquois" moraine is simply the continuation of the Marseilles morainic system and was produced entirely by the Illinois lobe. This is the simplest interpretation of the three and seems to be the best supported, for the others lack the evidence necessary fully to establish the complex history postulated for them. If the "Iroquois" morainic tract be examined in cross section it is found to resemble the Marseilles in amount of relief, in breadth, and in having a long gradual slope on its north or iceward side, and a rather abrupt descent on its south or landward side. The rise from the plain to the crest of the moraine on the north amounts to 20 to 40 feet in about 2 miles and on the south to 30 to 50 feet in less than 1 mile. These similarities and the further fact that the "Iroquois" moraine lies in the line of natural continuation of the Marseilles system strongly favor the third view.

The width of the "Iroquois" moraine is generally between 2 and 4 miles, but bowldery areas on its north border extend about 2 miles farther north to the southern edge of an extensive sandy plain traversed by Kankakee River.

The southern border of the "Iroquois" moraine lies 1 to 4 miles north of Iroquois River in Newton and Jasper counties, Ind., and trends south of west and north of east. In eastern Jasper County it turns northward and extends nearly to the northeast corner of the county. It dies out as a definite ridge 4 or 5 miles south of Kankakee River, and its continuation to the east is uncertain.

Inasmuch as this moraine dies out at the northeast in a sandy plain, some uncertainty is felt as to its continuation farther east. One possible correlative is a moraine which begins near Bass Lake, in Starke County, about 18 miles to the east. Between the two lies a tract which, though generally sand covered, bears a broad low ridge from the north end of the "Iroquois" moraine at San Pierre to North Judson and carries patches of bowlder-strewn till from North Judson to Bass Lake, thus nearly filling in the interval between the ends of the well-defined moraines and giving some strength to the correlation. The correlative moraine, which leads southeastward from Bass Lake, appears to have been formed by the Saginaw lobe, for it lies on the immediate outer border of the great Maxinkuckee moraine of that lobe, discussed below.

TOPOGRAPHY.

The highest points noted on the Marseilles system in the district north of Iroquois River are north of Rensselaer, where an altitude of 765 to 775 feet above sea level is attained. Much of the moraine reaches between 700 and 725 feet.

The surface of the ridge carries low knolls and ridges, among which sloughs and shallow basins are inclosed. Part of the bowlder-strewn plain north of the ridge is also occupied by low swells and hummocks, among which are shallow basins, but much of it is flat.

STRUCTURE OF THE DRIFT.

The depth to rock is only 40 to 50 feet in the northeastern part of the moraine from near San Pierre to Kankakee River, but increases to nearly 100 feet within a few miles south of San Pierre and on the high part of the moraine north of Rensselaer has not been reached by some wells nearly 200 feet deep. The general depth from Rensselaer westward is about 125 feet.

The basal portion of the drift is an indurated till, 35 to 40 feet thick, probably of pre-Wisconsin age. Above it is a very clayey, easily penetrated till, which is thought to be Wisconsin drift, and which forms the body of the ridge and gives it relief above the bordering plains. The surface portion to a depth of 5 to 20 feet differs markedly from the underlying clayey till, showing many abrupt changes from sand to clay. The sand has a somewhat singular distribution, capping many of the knolls to a depth of a few feet and being absent from many of the contiguous lower tracts. Northward from the ridged portion of the moraine across the bowlder-strewn plain sand patches become more and more noticeable until they coalesce in a continuous sheet. Bowlders abound in portions of the ridged part and are common over the entire ridge; they occur, however, in greatest number on the plain north of the ridge. Most of them are of granite and other crystalline rocks of Canadian derivation, but many are limestone fragments of local derivation. In an excavation at Brook, just south of the moraine, a collection of pebbles 1½ inches or less in diameter, taken in order as they appeared on the slope, was made up of the following rocks:

Pebbles in till near Brook, Ind.

Limestone, chiefly gray	56
Shale, sandy	4
Chert, probably from the limestone	3
Quartz	2
Granite	6
Greenstone	8
	79

Several wells along the ridge and in the border plain pass from soft, easily excavated till of Wisconsin age to hard, partly cemented till, probably of Illinoian age. North of Rensselaer, in sec. 30, T. 30 N., R. 6 W., two wells reach the bottom of the soft drift at 90 feet, and a third at 97 feet. The first two were extended through a hard till to water-bearing sand at 130 and 147 feet, but the third found water between the two sheets of drift. South of the moraine, in the vicinity of Brook, a soft till extends to a depth of 50 or 60 feet, below which a harder till extends either to the rock or to water-bearing beds. About 5 miles northwest of Kentland, in sec. 13, T. 27 N., R. 10 W., four wells on the farm of J. V. Speck are reported to have passed, at about 80 feet, through a brown swamp muck representing an old land surface at the bottom of the till, beneath which they entered water-bearing sand and gravel. In the vicinity of Donovan, Ill., several wells pass, at about 100 feet, from soft into hard till, below which, at about 140 feet, lies black muck, underlain by another till sheet. Records of several wells along the line of the ridge make no mention of a change from soft to hard till at depths corresponding to those just reported, but this lack may be due to less close observation. The thickness of the drift approaches 200 feet in some of the wells.

A well on Mr. Peterson's farm near the State line, in sec. 11, T. 28 N., R. 10 W., on a high part of the moraine, penetrated 168 feet of drift, of which the lower 8 feet was water-bearing sand and the remainder till. A neighbor's well 171 feet deep passed through 165 feet of till before striking water-bearing sand.

At Morocco, on the north slope of the moraine, a boring at the creamery penetrated 127 feet of till to limestone. Several wells near the range line east of Morocco enter rock at 110 to 120 feet after penetrating a solid bed of till.

At Mount Ayer, also on the moraine, a few wells put down to 140 to 160 feet extend but little into rock. The drift in Mr. Ashby's well has the section given below, Lewis Marion's strikes shale rock at 139 feet, and W. J. Young's at 150 feet, the wells being mainly through till to these depths.

Section of drift in Ashby well at Mount Ayer, Ind.

	Feet.
Till, yellow	10
Sand, blue	20
Till, blue	90
Shale, blue	20
Rock, hard, flinty.	
	140

Two wells at Surrey that enter rock at 90 feet are mainly through till. Several borings 2 or 3 miles north of Surrey strike rock at 80 or 90 feet. On the crest of the moraine southeast of Surrey at Charles Coen's, in sec. 12, T. 29 N., R. 7 W., a well strikes rock at 192 feet and there obtains water. At William Nowel's, in the same section, a well strikes rock at 140 feet and obtains water at 162 feet. In both wells the drift is mainly till.

A well on the moraine southwest of Medaryville, in sec. 13, T. 30 N., R. 5 W., penetrates 102 feet of drift, mainly blue till; another in the same section penetrates 80 feet. A well at Mr. Osborne's, in sec. 1 of the same township, has 126 feet of drift, and one at Mr. Rayburn's, in sec. 2, has 118 feet. A well at the tile factory in Medaryville passed through 92 feet of drift and obtained water from the rock at 115 feet. A prospect boring for gas shows the drift at North Judson to be 198 feet thick.

From North Judson a heavy body of drift extends eastward across northern Indiana. The rock surface appears to be somewhat lower along the line of this moraine than a few miles south of it, for the drift is very thin in southwestern Pulaski and in much of southern Jasper and Newton counties. The rock also appears to be higher north of the moraine in a small tract near the corners of Starke, Jasper, Porter, and Laporte counties, several oil wells having entered it at 50 feet or less.

SAND OF KANKAKEE-TIPPECANOE AREA.

The sand of the Kankakee-Tippecanoe area was discussed in Monograph XXXVIII as a deposit of Lake Kankakee, though it was pointed out that the "lake" seemed to consist not of any general body of water, but merely of small shallow marshlike areas not very different from those of the present Kankakee Marsh. It was suggested by Chamberlin [1] that the great accumulations of sand are probably referable to outwash from adjacent ice lobes, the Lake Michigan lobe bordering the area on the north and the Erie-Saginaw lobe on the east. Subsequent investigations have sustained this idea and have brought out evidence that points to a northward and eastward enlargement of the sand area during the recession of the ice lobe. The existence of certain low-lying tracts strewn with bowlders and nearly free from sand amid bordering higher sand-covered areas suggests that patches of stagnant ice persisted while the sand was being laid down. By the time the stagnant ice had disappeared the deposition of the sand seems to have been practically completed in much of the area south of the Kankakee Marsh.

If the deposition of the sand was progressive, it probably began along a belt which runs westward for 20 miles from Monticello through White and northern Benton counties, nearly parallel with the Nebo-Gilboa ridge and distant from it scarcely 3 miles. It has in places the narrow, definitely ridged form of a shore line, being 100 to 200 yards in width and 10 feet or less in height, but it varies in altitude in a manner inconsistent with its being a shore feature. It ranges from 675 up to fully 750 feet above tide, rising from Monticello westward to about the meridian of Goodland and beyond that point descending to a western terminus near Kentland nearly as low as its beginning at Monticello. Its parallelism to the Nebo-Gilboa ridge suggests that it is an ice-border feature formed probably in a manner similar to an outwash apron. The higher land to the south would prevent the spread of the sandy outwash beyond the immediate edge of the ice, and thus account for the narrowness of the sand belt. Some of the ridging may have been produced by wind action.

On theoretical grounds it seems probable that ponded conditions prevailed in the district south of the Marseilles morainic system during its development. The basin now drained north-

[1] Preliminary paper on the terminal moraine of the second glacial epoch: Third Ann. Rept. U. S. Geol. Survey, 1883, p. 330.

ward by Iroquois River into Kankakee River would have been prevented by the ice sheet from draining in that direction, and it probably discharged across a low point on the western rim of the basin to the east fork of Vermilion River in northern Ford County, Ill.[1] The distribution of the sand deposits in the Iroquois basin lends support to this interpretation. A sand ridge leading through Onarga and Ridgeville, Ill., at an altitude of about 675 feet above sea level, is thought to mark the southern edge of the lake in the western part of the basin and to indicate its height. There may also have been an eastward discharge from the basin past Monon, Ind., into Monon Creek and thence to Tippecanoe and Wabash rivers. A long sand ridge leading eastward from the meridian of Goodland, Ind., nearly to Monon stands at about 675 to 680 feet and probably marks the southern edge of the lake. Nearly all the sand in the Iroquois basin is below the level of these sand ridges, and the portion above does not conform to the conditions of a lake shore. Its ridges rise and fall in their course across the country and seem to have been developed by wind rather than by water. In places a fine silt has been deposited within the area supposed to have been covered by the lake; one such locality was noted a few miles southwest of Rensselaer, Ind., and another in Iroquois County, Ill., between Watseka and Donovan.

Sandy areas farther east in the district between Monon Creek and Tippecanoe River, like those east of the Tippecanoe in Pulaski and White counties, were probably laid down in connection with the recession of the Erie-Saginaw portion of the ice sheet. The headwater portion of Monon Creek is in a bowlder-strewn basin nearly surrounded by slightly higher sandy tracts. This basin, which occupies an area of about 25 square miles, may perhaps have held a mass of stagnant ice during the deposition of the surrounding sand deposits. Similar depressions near Winamac and above that village along the borders of Tippecanoe River seem to mark places where the ice persisted during the deposition of sand over the bordering district. Some small areas free from sand in southeastern Starke County, both southwest and west of Bass Lake, may perhaps be explained in the same way.

Outside of the Valparaiso morainic system and its gravel outwash the Kankakee basin is covered by sand except over a small area in southwestern Starke and northeastern Jasper counties where a bowldery till forms the surface. The altitude of this till area is between 660 and 670 feet, somewhat lower than that of the surrounding sand-covered tracts and 30 to 40 feet lower than that of the sand 2 or 3 miles to the south. As in the districts to the east, the absence of the sand from this low tract may be due to its occupation by ice during the deposition of the sand.

Considerable attention has been given to the slope of the sandy tracts with a view to determining the direction in which the waters probably flowed. In the Kankakee basin they seem to have flowed westward from the time the Lake Michigan ice lobe shrank away from the southern edge of the valley. In the Iroquois basin they probably flowed westward, though, as just indicated, they may have been ponded to some extent south of the Marseilles morainic system. In the Tippecanoe basin conditions are more complex: The river flows chiefly among moraines for more than half its length before entering this sand area. At its point of entry near Ora (see Pl. VI) it is closest to Kankakee River. From this point the sandy plain slopes northwestward toward the Kankakee as well as southwestward into the territory traversed by the Tippecanoe, forming a very flat alluvial cone. This suggests a spreading of drainage from this part of the Tippecanoe during the height of the glacial floods. The present stream for some 25 miles below Ora takes a zigzag course through a series of bowlder-strewn depressions which the sand did not fill and which, as already suggested, may have been occupied by remnants of the ice sheet during the deposition of the sand. The sand on the western side slopes away from the river toward Monon Creek, continuing the southwestward slope it had on the eastern side. Thus Monon Creek, although a tributary of the Tippecanoe, flows through a district lower than that of the main stream. The divide between Monon Creek and the headwaters of the Iroquois is very low and flat, especially south of the Marseilles morainic system, and the general south-

[1] Leverett, Frank, The Illinois glacial lobe: Mon. U. S. Geol. Survey, vol. 38, 1899, pp. 289-290, 314.

westward slope is continued into the Iroquois basin. The valley of the creek, however, is a broad slough which, like the depressions along the Tippecanoe below Ora, has diverted the drainage to a course out of harmony with the general slope. It seems probable, therefore, that from much of Pulaski County now drained southward there was a southwestward glacial drainage to the Iroquois and that from near Ora in Starke County there may have been a northwestward drainage to the Kankakee as well as a southwestward drainage to the Iroquois. Below the junction of Monon Creek and Tippecanoe River there may have been a southward drainage to the Wabash, but if so it seems not to have distributed the sand far in that direction, unless along the immediate valley of Tippecanoe River. Possibly the lower course of the Tippecanoe was still occupied by the Erie lobe and drainage in that direction was prevented until the deposition of the sand was essentially completed.

Throughout this area the sand is generally free from coarse pebbly material and appears, therefore, to have been deposited by streams with rather sluggish currents, as would be expected from their very gradual descent and their great breadth. The present Kankakee, from its source near South Bend to the State line of Indiana and Illinois, descends about 15 inches to the mile, yet because of its breadth in the marsh it is capable of transporting only fine sand. The slope of the Kankakee Marsh, however, appears to be greater than the average slope in the parts of the Tippecanoe and Iroquois drainage basins where the sand was deposited.

The depth of the sand probably corresponds to its relief above the bordering clay plains (10 to 25 feet, with an average of perhaps 15 feet), for wells find water in it at about the level of the clay. Along the Kankakee Valley sand appears to be heavier as well as more extensive than in the Tippecanoe and Iroquois basins. It is thought that much of the sand was brought into the Kankakee basin by glacial streams that discharged through St. Joseph River during the recession of the ice into southern Michigan, and that it was thus collected from a much larger area than that tributary to sand-covered parts of the Iroquois and Tippecanoe basins.

Some weak morainic ridges along the eastern edge of the sand-covered area come up for consideration more naturally in connection with the Maxinkuckee moraine, with which they seem to have close relations. (See p. 132.) The extensive outwash apron of gravel and sand north of the Kankakee is also more appropriately considered in connection with the morainic systems of the Lake Michigan lobe in that region. (See pp. 175, 180.)

STRIÆ.

Observations on striæ made by Chamberlin at Monon and near Kentland, indicate two ice movements, an earlier one southward and a later one westward. The later movement fits in well with the Wisconsin and is probably referable to it, and the earlier or southward movement may be Illinoian. Southward-bearing striæ found at Rensselaer may also have been formed prior to the Wisconsin ice invasion.

MAXINKUCKEE MORAINE AND ASSOCIATED GLACIAL FEATURES.

COURSE AND DISTRIBUTION.

A great belt of very irregular-surfaced drift 5 to 15 miles wide leads southward from South Bend about 40 miles to the Tippecanoe Valley opposite Rochester, Ind. Except at its northern end, which may have been touched by the Lake Michigan lobe, it seems to have been formed by ice that lay on its east side. The moraine takes its name from Lake Maxinkuckee, which stands in its broadest part a few miles northwest of Rochester.

The great breadth of the moraine in the vicinity of Tippecanoe River compared with its breadth near South Bend indicates that the ice was not holding its position in the former locality so firmly as in the latter. South of the Tippecanoe the recession seems to have been still more rapid; well-defined moraines are wanting, only narrow strips and interrupted patches of undulating land interrupting an otherwise flat-surfaced country. The recession probably extended across the entire breadth of Fulton County into southern Marshall and western Kosciusko counties during the development of the well-defined ridge north of Tippecanoe River. It was by

this rapid recession in the district south of the Tippecanoe that the Saginaw lobe became differentiated from the Erie.

The best defined of the weak undulating strips leading southward from the Tippecanoe Valley passes east of south along the east side of Bruce Lake to Kewanna, where it swings around toward Royal Center and runs west of south to the Wabash Valley at Lake Cicott, about 10 miles west of Logansport. From Lake Cicott it is probably continued westward by a line of bowldery ridges leading past Idaville and dying out east of Monticello. Kewanna stands in a reentrant that apparently marks an incipient separation between the Saginaw and the Erie lobes, for the portion of the moraine to the south conforms more nearly with the trend of a moraine of the Erie lobe lying north of the Wabash than with the moraine of the Saginaw lobe under discussion.

A still weaker belt of undulating drift, a few miles west of the one just outlined, leads off southwestward to Thornhope and marks a still earlier position of the Erie lobe. The Saginaw equivalent seems to be found in ridges northwest of Bruce Lake in the bend of Tippecanoe River near Ora.

A ridge connects at the southeast with the Maxinkuckee moraine west of Lake Maxinkuckee, but leads away from it northwestward to Bass Lake in Starke County. It is 1 to 1½ miles wide and seems to mark a position held by the ice before the reentrant between the Saginaw and Lake Michigan lobes had receded to the head of Kankakee River. It may prove to be a correlative of the Marseilles morainic system of the Illinois lobe (p. 126).

The continuation of the inner or eastern portion of the Maxinkuckee moraine probably embraces a gently undulating tract north of Tippecanoe River in southern Marshall County. On entering Kosciusko County it passes to the south side of the river and forms a chain of weak ridges lying north of Burkitt. It connects with a large moraine of the Erie lobe near Claypool, a few miles south of Warsaw.

On the north border of this gently undulating tract a disjointed, narrow morainic ridge about 40 miles long, known as the Bremen moraine, runs past Bremen, Heckton, and Millwood and connects with the Maxinkuckee moraine at its northwest end near Lakeville and with the moraine of the Erie lobe at its southeast end near Warsaw. The country is decidedly flatter to the north of this ridge than to the south, so it gives a definite inner limit to the Maxinkuckee moraine and associated undulating tracts.

TOPOGRAPHY.

MAIN RIDGE NORTH OF TIPPECANOE RIVER.

In the district north of the Tippecanoe the Maxinkuckee moraine is topographically conspicuous from the plain that borders it on the west. The plain has an elevation of 720 to 750 feet along the border of the moraine. The moraine is largely above 800 feet and has points that closely approach 900 feet, the altitude at Penn geodetic station, 3 miles southeast of South Bend, being 897 feet and at a railway summit 4 miles south of Argos 887 feet. The region around Lake Maxinkuckee falls a little below 800 feet in general elevation, but ranges from 650 feet in the deepest part of the lake to 875 feet on the highest hills east of the lake.

Although so prominent from the outer border the moraine is relatively inconspicuous from the inner border, and grades, in Marshall County, into a gently undulating tract that stands nearly as high as the crest of the moraine.

Considerable variety of expression is found along the main belt between South Bend and Tippecanoe River. From the St. Joseph River bluff at South Bend southward to Potato Creek, a distance of 10 or 12 miles, many knolls rise abruptly to heights of 50 or 60 feet; among them are inclosed basins and sloughs. From Potato to Pine Creek, a distance of 10 miles, swells are usually 20 feet or less in height and the slopes gentle; shallow basins, however, are numerous. The expression is somewhat stronger toward the inner or eastern border than along the outer border. Pine Creek and streams near it are bordered by broad marshy tracts that give the outer edge of the moraine a ragged outline. The interfluvial tracts show an increase in ruggedness southward from Pine Creek, and opposite Plymouth knolls 30 to 50 feet in height appear.

North of the outlet of Twin Lakes, in sec. 18, T. 33 N., R. 1 E., a gravel knoll rises abruptly about 100 feet above the level of the outlet. A gently undulating tract between Twin Lakes outlet and Yellow River grades into an outwash apron. Some of the knolls bordering Lake Maxinkuckee rise 75 feet above the lake and 30 to 50 feet above low tracts on the east. The moraine is most prominent on the north and east sides of the lake. A few miles east of Lake Maxinkuckee, just north of the village of Walnut, a small tract contains several knolls 30 to 40 feet high with interspersed basins and sloughs. The common topography, however, in southern Marshall and northern Fulton counties is less sharply morainic, most of the swells and ridges being but 10 to 25 feet high, and basins are uncommon.

The weak outlying morainic belt in the southeastern part of Starke County has a few knolls 25 to 30 feet high, interspersed with tracts of gentle undulation and broken for about 1½ miles midway of its length with a gap filled with sand ridges. Although weak when compared with the Maxinkuckee moraine this moraine is in striking contrast to the bordering plains on which there are no knolls.

MAIN RIDGE SOUTH OF TIPPECANOE RIVER.

The undulating belt south of the Tippecanoe has few if any points exceeding 800 feet, most of it being between 760 and 800 feet, and is relatively inconspicuous from either side. Though its surface is decidedly more undulatory than that of the bordering plains, knolls exceeding 25 feet in height are rare, the majority being but 10 to 15 feet. In the feeble outlying belt south of the Tippecanoe the highest knolls reach about 20 feet and many are scarcely 10 feet high. They are on the whole less conspicuous than the outlying sand ridges.

In northern Cass and southern Fulton counties a bowldery belt lies in a plain as smooth as that on either side, swells 10 feet in height being rare. Its altitude, however, is high, being about 800 feet. For some miles it follows the divide between Eel River on the south and Tippecanoe River on the north. From its northeastern end northward to Rochester the undulation is greater, swells 10 to 20 feet high being common, and a sharp ridge in secs. 16 and 21, T. 30 N., R. 3 E., reaches about 40 feet.

INTERMORAINIC DISTRICT.

In the district between the main ridge and the Bremen moraine swampy basins or depressions are numerous, probably one-fourth of the surface being occupied by them. Most of the dry land has a wavy or gently undulating surface. Most knolls are but 10 or 12 feet high and few of them reach 20 feet. The features are such as might result from a rapidly receding ice border. The most prominent ridge noted is one just west of Atwood, in western Kosciusko County. It rises about 40 feet above surrounding country, is a mile in length, and nearly one-half mile in width. A cut in its northeast end, made by the Pittsburgh, Fort Wayne & Chicago Railway (Pennsylvania Railroad), is 25 feet in depth, and the roadbed of the railroad is raised slightly to pass through it.

STRUCTURE OF THE DRIFT.

COMPOSITION.

In the district north of the Tippecanoe, not only in the main moraine but in the gently undulating tract east of it, the drift is largely of gravel and sand or of sandy till. The part between South Bend and Potato Creek shows abrupt changes from gravel to till, knolls largely composed of gravel standing next to knolls largely composed of till, and some single knolls showing abrupt changes from gravel to till. The portion of the moraine between Potato and Pine creeks is composed more largely of clayey till than any other equal-sized area north of the Tippecanoe. From Pine Creek southward past Twin Lakes and Lake Maxinkuckee gravel and sand are commonly found in knolls in association with loose-textured till. East of Lake Maxinkuckee some clayey till is found, but as a rule the drift is loose textured and more or less gravelly.

BOWLDERS.

Surface bowlders are numerous north of the Tippecanoe, averaging perhaps 1,000 to the square mile on all the dry land of the district. They seem fully as abundant on the gently undulating tract between Tippecanoe and Yellow rivers as on the Maxinkuckee moraine but are rare in the swamps, perhaps because buried underneath the muck and organic growths. Most of them are of granite, but a very few, not more than a fraction of 1 per cent of those exposed, are of a red, jaspery conglomerate. They are generally small enough to be easily gathered up or buried by the residents, their common diameter being 2 to 3 feet.

In the district south of the Tippecanoe the drift in the undulating belts as well as in the plains is largely a clayey till. It is not rare, however, to find small knolls and ridges of sand or sandy gravel on prominent points or capping till swells. Few, however, contain gravel suitable for road ballast, and some seem to contain no pebbles.

South of the Tippecanoe bowlders are abundant only in certain belts, one running southward to Kewanna from the Tippecanoe Valley, and another running northeast and southwest through southern Fulton and northern Cass counties. (See Pl. VI.) In the former bowlders are no more conspicuous than in the district north of Tippecanoe River; in the latter they are much more numerous, numbering several thousand to the square mile. Granite far outnumbers all other kinds. The common diameter, as in the district north of the Tippecanoe, is 2 to 3 feet; those exceeding 5 or 6 feet are rare.

THICKNESS.

Depth to rock.—In the district occupied by the Maxinkuckee moraine and associated bowlder belts and undulating tracts the drift is very thick. The least thickness reported is 90 feet (at Royal Center) and the greatest thickness may exceed 300 feet. Reported thicknesses are set forth in the following table:

Deep borings on or near Maxinkuckee moraine.

Location.	Altitude of surface.	Thickness of drift.	Altitude of rock surface.
	Feet.	*Feet.*	*Feet.*
South Bend	725	137	588
Plymouth	780	242	538
Lake Maxinkuckee (Moorman boring)	754	203+	551 or less.
Rochester	800	155 245	645 555
Warsaw	824	255 247	569 577
Warsaw, 3 miles west of	820±	243	577±
Kewanna	785	167 208	618 577
Royal Center	734	90 109	644 625

If the rock surface has the same altitude beneath the Penn geodetic station, 3 miles southeast of South Bend, as at South Bend the thickness at the former place is over 300 feet. If it is the same on the crest of the moraine west of Plymouth as at Plymouth the thickness is about 300 feet.

If the rock is as low under the hills east of Maxinkuckee Lake as in the Moorman boring at the lake, the drift on the hills exceeds 324 feet, for the Moorman boring on ground only 20 feet above lake level failed to reach rock at a depth of 203 feet.

Probably a considerable part of the drift was deposited before the Wisconsin stage of glaciation, but the data concerning the character of this deeper part are insufficient to fix its contact with the Wisconsin drift.

The relief of the moraine above the districts to the west seems to be entirely due to Wisconsin drift, and this would justify the reference of between 50 and 100 feet of drift to this latest stage of glaciation. The depth of Lake Maxinkuckee (80 to 90 feet) carries its bed below the level of the plain outside the moraine and suggests that considerable filling may have occurred

on the plain as well as on the moraine and that somewhat more than 100 feet of drift was deposited at the last glaciation. The difference in level between the bed of Lake Maxinkuckee and the highest hills east of the lake is 225 feet, and possibly these hills were built up at this latest stage from a level as low as the lake bed.

Flowing wells.—Flowing wells are obtained in the low tracts along the moraine from Lake Maxinkuckee northward. They are reported to pass through considerable clay before entering the bed from which the flows are obtained. Data were obtained in five distinct districts—around Lake Maxinkuckee, in Yellow River valley at Plymouth, near Teegarden on a low part of the moraine, in Potato Creek valley east of North Liberty, and in the St. Joseph Valley at South Bend.

The flows around Lake Maxinkuckee are obtained at various depths from 13 feet up to about 100 feet. The following record of A. H. Culver's well[1] illustrates the structure of the drift in one of the deeper wells:

Record of Culver well.

	Feet.
Soil and yellow clay	8
Sand	14
Clay, blue	38
Sand and gravel	12
	72

Another boring, 98 feet deep, passed through yellow clay 11 feet, sand 25 feet, blue clay 62 feet, and failed to reach the bottom, the flow being from sand above the clay. The Peru Club sunk a well to a depth of 160 feet and stopped in "obdurate hardpan;" it obtained a weak flow from a sand bed higher than the hardpan. The deepest boring of which the present writer obtained data was sunk by D. W. Morman to a depth of 203 feet, obtaining a flow at about 100 feet. The head is reported[2] to be sufficient in parts of the basin to carry water 31 feet above the lake (765 feet above sea level), but in the Morman boring the water stands 13 feet below the surface and only 7 feet above the lake. The various depths at which the flows are obtained and the difference in head and strength of flow indicate that the bedding and texture of the gravel of the drift are very irregular.

In the flowing wells at Plymouth the depth to the water bed is about 40 feet, but some wells are carried deeper. Records furnished by a driller indicate little besides sand, interspersed with beds termed "hardpan," 2 to 5 feet thick.

In the Teegarden district, which extends down Yellowbank Creek 2 or 3 miles from Teegarden, the wells are mainly through blue till and range in depth from 40 feet to about 100 feet.

In Potato Creek valley east of North Liberty two flowing wells, 45 and 70 feet deep, were reported to be largely through till. A well on the gravel plain about a mile southwest of North Liberty, in sec. 5, T. 35 N., R. 1 E., is reported by the driller to be entirely through sand and gravel to a depth of 160 feet. The water heads 1¼ feet below the surface.

In the St. Joseph Valley at South Bend flowing wells have been obtained for the waterworks supply from sand underlying a bed of stiff clay reported to be nearly pebbleless. There were at the time of the writer's visit in 1902 thirty 6-inch wells about 100 feet deep, with head 5 or 6 feet above the surface and yielding by pumping at least 10,000,000 gallons a day.

The gas boring made by Mr. Oliver at South Bend is reported by Phinney to have penetrated the following drift beds: Sand, 25 feet; gravel, 20 feet; clay, 30 feet; sand, 25 feet; gravel, 37 feet.

Deep wells.—Records of several other wells of considerable depth were obtained. Two, on a prominent part of the moraine about 8 miles from South Bend, in sec. 17, T. 36 N., R. 2 E., are 131 and 146 feet deep; neither reaches rock. A well on the farm of Mr. Sweeney passed through 22 feet of yellow till, a thin bed of sand, and blue till and sand in alternate beds a few feet thick to the bottom of the well.

[1] Fifteenth Rept. Indiana Dept. Geology and Nat. Hist., 1887, p. 184.
[2] Idem, p. 185.

The gas boring at Plymouth which extended some depth into rock penetrated 240 feet of drift as follows: Sand and gravel, 40 feet; till, 50 feet; mainly sand and gravel, 150 feet.

Records of two wells west of Lake Maxinkuckee, in the eastern edge of Starke County, show contrast in drift structure. One on the farm of David Fetter, in sec. 13, T. 32 N., R. 1 W., penetrated sandy till, 5 feet; blue till, 12 feet; quicksand, 5 feet; blue till, 30 feet; sand and gravel, 2 feet. The other, on the Pettis farm, in sec. 24, penetrated soil and yellow till, 12 feet; blue till, 16 feet; gray sand, 52 feet; blue clay, 4 feet; cemented sand and gravel with perhaps some clay, 15 feet.

West of the wells just noted, past Bass Lake to Round Lake and Aldine, blue clay is present at slight depth in many of the wells. Bowlders are also conspicuous from Lake Maxinkuckee westward to Bass Lake on nearly plane tracts and on morainic tracts.

A boring at Bremen, in the west part of the village, reached a depth of 100 feet, mainly through blue till. The common depth of wells at Bremen is 30 to 40 feet, largely through till.

At Inwood wells are mainly through sand and gravel or sandy till, though thin beds of "clay" are reported to occur.

Records of gas borings made some years ago at Rochester show alternations of till with sand and gravel, but give no details of structure.

Gas borings at Kewanna penetrated considerable sand and gravel and some thin beds of blue till. Farm wells in the vicinity of Kewanna pass through considerable blue till; one in sec. 28, T. 30 N., R. 1 E., is 120 feet deep, but most of them are less than 50 feet deep.

At Royal Center oil wells penetrate 90 to 109 feet of drift. In some wells gravel between the surface clay and the blue till yields water at a depth of 10 feet or less. Other wells penetrate about 40 feet of blue till to reach a lower gravel bed at 50 feet. The oil-well borings are reported by Elrod to have passed through "gravel mixed with yellow clay" in the lower part of the drift. Two deep farm wells east of Royal Center, reported by Elrod, show considerable contrast in drift beds. One in sec. 21, T. 28 N., R. 2 E., entered blue till at 15 feet and continued in it to 130 feet. Another, 93 feet deep, in sec. 27 struck no blue till, penetrating sandy loam, 6 feet; fine gravel, 8 feet; yellow clay, 12 feet; gravel, 8 feet; quicksand, 56 feet; coarse water-bearing gravel, 3 feet.

OUTWASH.

The outwash connected with the Maxinkuckee moraine embraces not only material spread out along the outer border of the moraine, but also gravel and sand plains heading near the inner border and leading through the moraine, and perhaps also much of the undulating tract between the moraine and the Bremen moraine.

OUTWASH FROM OUTER BORDER.

Along the outer border of the Maxinkuckee moraine from South Bend southward to Yellow River valley a gravelly plain has apparently been overspread to some extent with the outwash from the moraine. The part near the Kankakee in St. Joseph County was probably also affected by the Lake Michigan lobe during the development of the Kalamazoo morainic system. (See p. 175.) Gravel lies along and near the edge of the moraine but gives place to sand westward toward Kankakee River, scarcely a pebble being visible. As a rule wells in the gravel plain do not strike till, though many of them are 20 to 30 feet deep. One well 2½ miles south of Walkerton is reported to have passed through about 50 feet of pebbleless blue clay and terminated in fine sand under the clay at a depth of 80 feet.

At Yellow River the gravel plain extends back into the moraine nearly to the bend of the river south of Plymouth. It occupies nearly all the space between Twin Lakes and the river, a breadth of about 2 miles. The surface is rather sandy and is drifted in places into dunes, but is underlain by coarser material at slight depth. The gravel plain also extends up small valleys on the outer slope of the moraine north of Yellow River.

On the south side of Yellow River a till plain lies between the Maxinkuckee moraine and the outlying moraine that runs past Bass Lake. Outside or west of this outlying moraine a

sandy plain extends from Bass Lake to the Tippecanoe Valley at Monterey. Near Tippecanoe River there is some gravel. North of Monterey basins occur along the border of the gravel plain, which is here about 30 feet above Tippecanoe River.

A line of glacial drainage descends westward from the Maxinkuckee moraine just south of Culver station near the west shore of Lake Maxinkuckee to a tamarack swamp around Manitou Lake. Its surface is strewn with cobblestones and small bowlders and is indented by shallow basins. South of it a spur of the main moraine extends west nearly to the Starke County line in secs. 29, 30, 31, and 32, T. 32 N., R. 1 E. From Manitou Lake the water may have discharged either southward along the west edge of the morainic spur to the Tippecanoe Valley or may have continued westward through a gap in the outlying moraine in secs. 23, 26, and 27, T. 32 N., R. 1 W., to strike the Tippecanoe near Ora. Sand ridges on the outer slope of the Maxinkuckee moraine at many points from Lake Maxinkuckee northward to Pine Creek valley in the northwest township of Marshall County seem to have been heaped up by wind, but their sand was probably first laid down as an outwash from the ice sheet as it was melting away from the moraine.

Below Leiters Ford the north side of the Tippecanoe Valley is occupied by a plain 3 or 4 square miles in extent, which carries fine gravel at its surface. This plain seems to grade into the Maxinkuckee moraine at the north and east borders and was probably formed by direct outwash from that part of the ice border. It remains gravelly only to the outlet of Lake Maxinkuckee. West of that outlet for 2 or 3 miles fine sand lies along the north side of the river. Near Monterey the pitted gravel plain outside the small moraine leading past Bass Lake sets in.

From the character of the material in the Tippecanoe Valley it appears that in course of the retreat of the ice sheet from the outer to the inner edge of the morainic belt unusually vigorous outwash occurred in three places—one near Monterey, another near Leiters Ford, and a third above Rochester in the vicinity of Manitou Lake. The distribution of the plain, first on the left, then on the right bank of the river, was controlled by the altitude of the bordering districts, the country being lower on the left or south bank than on the north from Rochester down to Leiters Ford and opposite conditions obtaining below Leiters Ford.

South of the Tippecanoe Valley, for a short distance south from Monterey, a gravelly outwash plain, already noted, with westward slope fills the space between the two morainic tracts. It pertains to the eastern tract, the western one having only sand along its outer or western border.

Farther south the weak western belt has sand on its outer border at numerous points and has a nearly continuous sand border from the Mill Creek[1] valley southward to Lake Cicott. In northeastern White and northwestern Cass counties the sand plain is several miles wide, but in southeastern Pulaski County it is less than 1 mile wide.

The outwash from the eastern and stronger undulating belt is not well defined except at the immediate border of the Tippecanoe Valley, though it forms some sandy deposits and ridges. The sand carries few pebbles, and the ridging may be referable to wind action. The deposits are probably to be classed as outwash from the ice sheet, though their precise mode of deposition remains uncertain.

Mill Creek, which cuts through this undulating belt, is bordered by a swampy flood plain one-half mile or more in width for 2 or 3 miles above the intersection and in the passage through it; on leaving the undulating belt the swampy condition ceases, but the valley continues broad throughout its course to the Tippecanoe. It seems to have been utilized as a line of discharge for glacial waters either direct from the ice sheet or from a lake held in front of the ice on the eastern slope of the undulating belt. The deposits along the valley are sandy and do not show the coarseness to be expected along a strong stream, indicating that the gradient was so low that only sand was transported down the valley.

[1] This Mill Creek, which enters the Tippecanoe below Winamac, should be distinguished from one that enters the same river near Rochester.

INTERMORAINIC DISTRICT.

In the Tippecanoe Valley an extensive sandy plain extends over central and northwestern Fulton County. From Monterey up to Leiters Ford the plain is on the north side of the river, but above Leiters Ford it is on the south side. The plain extends southeastward from Rochester up the valley of Mill Creek past Manitou Lake [1] and apparently heads in a reentrant angle of the receding ice sheet between the Erie and Saginaw lobes. At the head there is an undulating surface with basins and low swells, such as often characterize outwash aprons. Manitou Lake, now a single body of water with an area of over a square mile, was formed by damming the outlet of a group of lakes that occupied several small basins in the plain. The sand plain has a definite south border in a sand ridge that runs from Mill Creek valley at Rochester westward to Mud Creek valley, descending about 30 feet (from 780 feet to 750 feet) in the 6 miles. On Mud Creek an extensive swamp, standing about 750 feet above sea level, is separated from the Tippecanoe by the sand plain, which seems to form a dam across the lower end of the Mud Creek valley. Probably for a considerable period the swamp was occupied by a lake, but the creek had cut its outlet sufficiently deep partly to drain it before the country was settled, and a system of ditches has since much reduced the swamp. The sand of the plain is rather light and drifts in places into dunes, of which the sand ridge along the south border is a conspicuous example. Wells, however, are reported to pass into fine gravel a few feet below the surface.

East of Kewanna, in secs. 24 and 25, T. 30 N., R. 1 E., and sec. 19, T. 30 N., R. 2 E., the plain between the undulating belt and the Mud Creek swamp is traversed by a network of sand ridges, which are 10 to 25 feet high and in places have the form of eskers. Gravel was found, however, on only one single high point at the western end of the system, and it remains to be determined whether the ridges are of esker-like origin or are simply due to wind. Indeed, the localization of the sand in this region is not as yet understood.

On Tippecanoe River below Warsaw a sandy plain that lies south of the stream appears more closely related to an ice border on that side than to the ridge that comes to Warsaw from the northwest. It may, however, consist of outwash from the reentrant angle at Warsaw, where the trend of the border changes from southeast to southwest.

BREMEN MORAINE AND INNER BORDER TILL PLAINS.

The Bremen moraine has its strongest development in the vicinity of Bremen, where it rises 20 to 25 feet above a marshy tract on the north and a gently undulating plain on the south. From Bremen to Hepton it forms a low basement ridge 10 to 15 feet high, bearing swells 10 to 20 feet in height. From Bremen westward to the Maxinkuckee moraine at Lakeville it is broken by many gaps, and where best developed its knolls reach scarcely 25 feet in height.

The ridge that sets in south of Hepton and runs southeastward to Warsaw has about the same strength as the ridge that leads to Hepton from Bremen. It consists of a low basement ridge with a relief of 10 to 15 feet, along which knolls 10 to 20 feet high are common. At its southeast end in the bend of Tippecanoe River north of Warsaw it rises into a series of sharp gravel knolls 30 to 50 feet high.

A sandy plain filling the gap south of Hepton has the appearance of the head of a line of glacial drainage, and sandy land extends from there down South Fork of Yellow River to its junction with North Fork a few miles below Bremen. This sand may be outwash from the small ridge on which Bremen stands, but its identification is uncertain because the valley may have afforded a line of discharge for water from a moraine farther east whose gravel plain extends about to the head of Yellow River. The later discharge, however, seems likely to have covered only a swampy tract about a mile wide along the river, leaving to the south a slightly higher plain, on which the hamlet of Millwood now stands, as a remnant of filling by outwash from the moraine at Bremen. North Fork of Yellow River, which crosses the moraine

[1] This Manitou Lake should be distinguished from the Manitou Lake west of Lake Maxinkuckee.

at Bremen, does not carry so well defined a sand plain and seems to have been at best a weak line of discharge. Yellow River has apparently a very low gradient from Bremen to Plymouth and this may account for the weakness of outwash. Sand ridges near the junction of the two forks suggest the former presence of a small lake, but to prove its existence will require further study.

Two till plains of considerable extent lie between the Maxinkuckee and the Bremen moraines. One is north of Yellow River in St. Joseph and Elkhart and on the edges of Kosciusko and Marshall counties; the other is southeast of Tippecanoe River in Kosciusko, Fulton, and Cass counties. The plain north of Yellow River has a general elevation of about 850 feet with a range from about 820 to 880 feet or more. It is very smooth with scarcely a knoll worthy of note. The drift is in large part a clayey till, though small areas with sandy soil were noted, the most conspicuous being near the Bremen moraine. Bowlders are far less numerous on its surface than on the tract south of Yellow River or on the main Maxinkuckee moraine to the west. Many dug wells obtain water from sand beds between the yellow and blue tills at depths of only 10 to 20 feet, but drilled and bored wells are carried to depths of 60 to 100 feet and penetrate more or less blue till.

The till plain south of the Tippecanoe gradually rises toward the southeast, or away from the river, from 750 to 850 feet above sea level. The bowldery strip of southern Fulton and northern Cass counties runs through the middle with an altitude of about 800 feet throughout its length of 15 miles or more. The southeastern edge of the till plain, which is determined by the outer border of a prominent moraine of the Erie lobe, passes near the villages of Claypool, Akron, and Macy. From the meridian of Rochester southwestward to Lucerne this plain has scarcely any knolls or ridges, but east of this meridian it bears small knolls and has a wavy surface. Its clayey till, occupied by beech, maple, and elm forests, put it in striking contrast with the looser-textured drift and oak forests of the morainic tract to the southeast. Many wells find water at moderate depths in sand between till sheets, but a few have been sunk 60 to 80 feet or more. The deeper ones are largely through blue till. Bowlders are rather common over all this plain but are especially numerous along the belt that runs from near Lucerne in Cass County northeastward across southern Fulton County to the two Mud lakes at the head of Mud Creek. This belt (p. 132) seems likely to mark the position of the ice border in a brief halt in its retreat to the line of the large moraine southeast of it. The bowlders outside this belt seem to be no more abundant than is natural to a rapidly receding ice border.

NEW PARIS MORAINE.

COURSE AND DISTRIBUTION.

The next-younger well-defined moraine of the Saginaw lobe is named from New Paris, a village in southern Elkhart County, that stands near one of its most prominent points. The moraine, as here interpreted, includes a somewhat loosely assembled series of undulating and knolly tracts that covers the northeastern part of Kosciusko County and leads northward through central Elkhart County to the St. Joseph Valley immediately southeast of the city of Elkhart. It embraces a strip 6 or 8 miles wide, only part of which can be said to have morainic topography. Its western edge in Elkhart County and its eastern edge in Kosciusko County are especially difficult to define. In eastern Kosciusko and southwestern Noble counties it connects with a strong moraine of the Huron-Erie lobe that crosses it nearly at right angles and runs southwest to Logansport. Its connections at the north are obscured by a sand plain that borders St. Joseph River, interposing a wide gap, north of which a later moraine occupies the district.

In northeastern Kosciusko County two somewhat distinct ridges are present. The outer one, which is only 7 or 8 miles long and scarcely 1 mile wide, leads northwestward from the moraine of the Huron-Erie lobe along the north side of the Barbee Lakes and Tippecanoe Lake across T. 33 N., R. 7 E., to Dewart Lake in the southeastern part of T. 34 N., R. 6 E.; it is separated from the inner ridge by a nearly plain tract 1 to 2 miles wide. The inner ridge parts

from the moraine of the Huron-Erie lobe in southern Noble County at High Lake, in the western part of T. 33 N., R. 9 E., and bears west-northwest across the north part of T. 33 N., R 8 E., entering Kosciusko County near Boydstown Lake, in the northeast part of T. 33 N., R. 7 E. Thence it bears northwestward across T. 34 N., Rs. 7 and 6 E., to Milford Junction, its inner border passing about a mile southwest of Turkey Lake, the largest lake in Indiana. In this distance of 20 miles or more from High Lake to Milford Junction it maintains a width of about 2 miles. North from Milford Junction, between Turkey Creek and Elkhart River, it is very strong, and west of Turkey Creek it is apparently continued by a gently undulating tract, which extends to the divide between Turkey and Little Bango creeks and which is in striking contrast with a very flat tract west of it. It continues northward with somewhat stronger expression along the west side of Elkhart River valley past Goshen to Yellow Creek, about 5 miles southeast of Elkhart. This brings it to the edge of the gravel plain of St. Joseph River, beyond which it has not been recognized.

TOPOGRAPHY.

Throughout much of its course this moraine rises only slightly above the outer border districts, a relief of 50 feet being rare. It has low swells with gentle slopes, a common height being 20 feet, though more fall below than exceed that height. Some knolls north of Boydstown Lake are 30 to 40 feet high and have steep slopes. "Waybright hill," a conspicuous irregular-shaped mass of drift about 2½ miles south of New Paris, is by far the most prominent feature of the moraine; it reaches an altitude (barometric) of 1,025 feet, or about 215 feet above New Paris station, and is spread over the south half of sec. 22 and much of sec. 27, T 35 N., R. 6 E. The remainder of the moraine in Elkhart County, except perhaps a few knolls 3 to 4 miles southwest of Goshen, is below the 900-foot contour, and the part in Kosciusko County reaches 900 feet only at the extreme eastern edge of the county. The portion in Noble County rises a little above 900 feet, with a few points near High Lake that approach 1,000 feet.

The portion of this moraine in Noble and Kosciusko counties has numerous lakes along its course and on its borders, but that in Elkhart County has only one lake of sufficient size to be represented on the county map. This forms the head of Yellow Creek and is located in sec. 34, T. 36 N., R. 5 E. The principal lakes are as follows: [1]

Lakes along or near New Paris moraine.

Name.	Location.			Area in acres.	Depth in feet.
	T. N.	R. E.	Secs.		
Turkey	34	7	4, 5, 8–11, 14–17, 22–26	[a]5.66	68
Dewart	34 34	7 6	25 30	300	60
Milford	34	6	21–22	175	52
Tippecanoe	33 33	6 7	1, 11, 12 6–9, 16–18	[a]1.61	[b]121
Boydstown	33	7	10–15	[a]1.057	43
Barbee Lakes [c]	33	7	20, 21, 26–29	(?)	19–42
Ridinger	32 33	7 7	1 36	300	45
Little Eagle	33	6	24–26, 35	700±	(?)
High	33 33	8 9	13 18	300 250	.... [d]36
Bear	33	9	7, 8, 17, 18	120 320	.... [e]57

[a] Square miles.
[b] The deepest lake depth reported in Indiana.
[c] A group of six small lakes.
[d] Lake lowered by ditching and depth reduced to 22 feet.
[e] Area and depth estimated by Prof. C. R. Dryer.

High Lake, as noted by Dryer in a special paper,[2] is nearly surrounded by sharp ridges of esker type distributed over an area of about 2 square miles. The most prominent ridge follows

[1] The areas and depths are from Blatchley, W. S., and Ashley, G. H., Twenty-fifth Ann. Rept. Dept. Geology and Nat. Res. Indiana, 1900, pp. 31–32, in which maps are presented showing the contours of the beds of several lakes.

[2] Jour. Geology, vol. 9, 1901, pp. 123–129, with sketch contour maps.

the south side of the lake and reaches a height of about 85 feet above it; in its highest part it incloses a kettle or basin which is at lake level. East and west of the lake basin are sandy and gravelly ridges 10 to 40 feet high. A short distance north of the lake a till ridge rises 50 to 60 feet above the lake and 30 to 40 feet above the general level of the country.

Five miles northwest of High Lake along the valley of Turkey Creek another system of esker-like ridges, noted and mapped by Dryer,[1] inclose the basin of a lake about 50 acres in extent, known as Gordys Lake. The main ridge is 15 to 30 feet high and connects at the north with a plexus of ridges and mounds of corresponding heights. The lake has a maximum depth of 35 feet. Dryer suggested the term "esker lakes" for lakes of this class, whose existence and outline depend so largely on the presence of eskers.[2]

STRUCTURE OF THE DRIFT.

In Noble County the moraine bears gravel knolls and short esker-like ridges as well as knolls and ridges of loose-textured till. In Kosciusko County it has fewer gravel knolls (though these are common near Boydstown Lake) and a more clayey till. In Elkhart County it has a conspicuous gravel accumulation in the massive knoll south of New Paris, but elsewhere is mainly till so far as exposed.

The most conspicuous gravel knolls in the tract west of Elkhart River and the ones drawn upon for ballast for miles around are near the corners of secs. 26, 27, 34, and 35 and along the line of secs. 21 and 22, T. 36 N., R. 5 E. Much of the moraine in Elkhart and Kosciusko counties is a clayey till which was once timbered with beech and maple.

Bowlders, mainly granite, are numerous all along the moraine and especially on the sharp knolls and ridges. A few of red jasper conglomerate were noted.

Few records of wells sufficiently deep to show the structure of the lower part of the drift were obtained. As a rule wells strike a water-bearing sand or gravel under a thin sheet of till, their depth being 20 to 30 feet.

Records of a few deep wells at farmhouses in the undulating tract west of Turkey Creek were obtained. The well of Solomon Pebble, in sec. 3, T. 35 N., R. 5 E., on ground about 875 feet above sea level, is 230 feet deep, and terminates in sand and gravel under a thick bed of till. The well of Noah Bare, in sec. 15, T. 35 N., R. 5 E., on ground about 860 feet above sea level, is 148 feet deep; it passes through yellow till, 10 feet; blue till, 100 feet; yellow till, 30 feet; gravel, 8 feet, bearing water having a head 60 feet below the surface. A neighboring well in sec. 16 is 175 feet deep. The well of James Brown, in sec. 36, T. 35 N., R. 5 E., on ground about 840 feet above sea level, is 106 feet deep; it passes through surface till for 40 feet, and is thence in sand and gravel to the bottom. Neighboring wells in sec. 30, T. 35 N., R. 6 E., are nearly 100 feet deep and are largely in blue till. The well of Charles Michael, in sec. 25, T. 36 N., R. 5 E., on ground about 880 feet above sea level, is 157 feet deep, largely through till; near the bottom it struck water that has a head 50 feet below the surface.

OUTWASH.

Along the outer or southwest face of the moraine from the Barbee Lakes and west end of Tippecanoe Lake to Milford is a gravel plain apparently formed as an outwash from the moraine. When first settled it was largely prairie, the part from Leesburg northward being known as Turkey Prairie and that near the west end of Tippecanoe Lake as Bone Prairie. A gravelly and sandy tract between the Barbee Lakes and Boydstown Lake in eastern Kosciusko County has a northwestward slope that seems to indicate derivation from the moraine of the Huron-Erie lobe which lies southeast of this tract, rather than from the moraine of the Saginaw lobe north of it.

A gravelly plain follows the Turkey Creek valley from Milford down to Elkhart River along the western or outer border of the main moraine. It continues down Elkhart River to the St.

[1] Loc. cit.

[2] Dryer also suggests that the plexus of ridges north of Gordys Lake forms an esker delta. In the present writer's opinion it is quite as likely to form the head of the esker, as eskers leading away from such a plexus are common. In this particular case also drainage is more likely to have been southward toward the ice margin than northward into the ice sheet.

Joseph, but in this portion, being inside the moraine, it can scarcely be regarded as the outwash from it. As indicated below, this gravel plain of Elkhart heads in later moraines in Noble County. The plain bordering Turkey Creek slopes from the New Paris moraine toward the creek as if formed as an outwash from it. The discharge from the portion of the ice border in Kosciusko County is likely to have been westward through Yellow River, but that from the portion farther north may have found escape along the Elkhart Valley under the edge of the small portion of the ice sheet that extended across that valley while the moraine was forming. No outwash was detected along the western edge of the undulating tract that lies west of Turkey Creek and Elkhart River, the country consisting of a flat till tract with fewer bowlders than the undulating tract.

INNER BORDER.

The district northeast of the New Paris moraine is exceptionally varied, comprising both flat and undulating till tracts, smooth and pitted gravel plains, lakes both in till tracts and gravel plains, glacial drainage channels, and bowlder belts, all in close association.

The most conspicuous till plain lies around and southeast of Turkey Lake in northeastern Kosciusko and western Noble counties. On the west and south it is bordered by morainic tracts and on the north by a sandy plain.

This sandy plain covers the northwestern part of Sparta Township (T. 34 N., R. 8 E.) and the southwestern part of Perry Township (T. 35 N., R. 8 E.) in Noble County and extends westward across the northeast corner of Kosciusko County and the southeast part of Elkhart County to the New Paris moraine. Near Ligonier it extends on the north to the bluff of Elkhart River, but farther west is cut off from the river by a narrow bowlder-strewn gently undulating till tract. The plain has its coarsest material at the northeastern edge and slopes southwestward or directly away from the river bluffs toward Solomon Creek, a small stream that heads in western Noble County and flows northwestward to Elkhart River through a channel whose depth is only 10 to 20 feet, though its width is about a mile. The portion of this shallow channel in Sparta Township, Noble County, is indented with basins containing swamps or small lakes. The distribution and character of the material as well as the slope of the sand plain indicate that it was built up as an outwash from the ice sheet at a temporary halt in the Saginaw lobe when it had receded about to the valley of Elkhart River in southeastern Elkhart and northwestern Noble counties. The Huron-Erie lobe probably stood at the eastern edge of the plain, and it is thought that the water from this lobe rather than that from the Saginaw cut the shallow channel along Solomon Creek. The junction of the two lobes at that time was probably near Ligonier. The Saginaw lobe, where not combined with the Huron-Erie lobe, appears to have developed no definite moraine on the border of the plain, but the Huron-Erie lobe has a strong moraine. (See p. 159.)

North of Elkhart River a gently undulating till tract several miles in width occupies the interval between the river valley and the next later moraine, the Middlebury. This till tract is traversed by a line of glacial drainage about a mile wide that leaves the Elkhart Valley about 2 miles east of Goshen and runs northward to Pine Creek and thence northwestward to the St. Joseph Valley east of Elkhart. Between this line of glacial drainage, which is known as the Canal Marsh, and the Elkhart Valley (which also was utilized as a line of glacial drainage) a tract of till with an area of about 16 square miles stands 30 to 50 feet above the bordering channels. The till is largely loose textured and bears on its surface many bowlders. The portion east of the meridian of Goshen has low swells and numerous basins, some of which are about 40 feet deep and are occupied by lakes. The portion northwest of Goshen has a relatively smooth surface with few basins.

East of the Canal Marsh channel the surface is gently undulating with swells 10 to 20 feet high and with very few basins. The altitude is generally about 900 feet or a little less, but in a group of knolls 6 miles east of Goshen it reaches 950 feet. The drift is somewhat more clayey than in the tract north of Goshen, but is on the whole a rather loose textured till. Bowlders are numerous over much of the surface and are especially abundant in a strip setting in about 5 miles east of Goshen and running eastward to the county line.

MIDDLEBURY MORAINE.

DISTRIBUTION AND CORRELATION.

A very prominent moraine in northeastern Elkhart County, Ind., is named from the village of Middlebury, by which it passes. It follows the south side of the Little Elkhart valley from western Lagrange County northwestward to the edge of the St. Joseph River valley, thence swings down the south side of the valley and dies out at the edge of the Canal Marsh channel, about 6 miles east of Elkhart. Its width along the St. Joseph is about 2½ miles, but along the Little Elkhart is scarcely 1 mile. It continues in faint form southward into the western edge of the southwestern township of Lagrange County, but dies out before reaching the Wabash Railroad.

With this moraine should probably be included a narrow morainic strip that follows the north side of Little Elkhart River from a point opposite Middlebury southeastward for about 6 miles, crosses to the south side of the river, and continues southeastward for 4 miles farther to the edge of a gravel plain known as the "Haw patch." Its course is nearly parallel with and only 1 to 1½ miles distant from the inner border of the Middlebury moraine.

At the southeast side of the "Haw patch" gravel plain is a moraine that in all probability was occupied by the Huron-Erie lobe during the development of the Middlebury moraine by the Saginaw lobe and the Lagrange moraine, discussed below.

The correlations to the north of St. Joseph River are somewhat uncertain. There is a strong moraine on the north side of the valley in the southern part of Cass County, Mich., but it is doubtful if it can be correlated with the Middlebury moraine so well as with a later moraine, the Lagrange, with which it is more nearly in line. It is possible the Lake Michigan lobe covered the St. Joseph Valley and the north end of the Middlebury moraine for a few miles east of Elkhart. Between the western end of the Middlebury moraine and the moraine north of the river in Cass County, Mich., is a gravel plain in which basins are conspicuous. Such plains are characteristic of an ice border, and this one apparently supports the view that the ice receded across the valley from the Middlebury moraine to the moraine in Cass County, Mich.

TOPOGRAPHY.

The Middlebury moraine stands above 900 feet except on the lower slopes toward St. Joseph River, where it drops down to little more than 800 feet. A prominent point about 2 miles northwest of Middlebury in the southern edge of York Township rises slightly above 1,000 feet, and the geodetic station 2 miles south of Bristol reaches 970 feet. The outer edge of the moraine comes down to about 900 feet throughout its course in Elkhart County and along the western edge of Lagrange County. The relief above the outer border district ranges from 10 or 15 up to 120 feet.

The small parallel eastern ridge is lower than the main moraine, its altitude being generally a little below 900 feet. It rises 20 to 50 feet above the valley of Little Elkhart River and about as much above a swamp that separates its southeastern end from the main moraine.

The portion bordering the St. Joseph Valley has a sharp knob and basin topography with numerous knolls 30 to 50 feet high and a few 75 to 100 feet. Basins and small lakes are inclosed among the knolls. The moraine is much less prominent from Middlebury southeastward, knolls being generally but 10 to 20 feet high and basins comparatively scarce. Basins in this part of the moraine are shallow and found chiefly along the outer border. The small inner ridge is characterized by knolls 10 to 25 feet high, some with steep but the majority with gentle slopes. Basins are not so conspicuous as in the main moraine.

STRUCTURE OF THE DRIFT.

The main moraine throughout its length, both in strong and weak portions, is composed largely of gravel or of very stony till. In places hundreds of large bowlders and thousands of cobblestones to the acre strew its surface. Scarcely any clayey till is present in Elkhart County, but it is not rare in Lagrange County, and it becomes still more common southeastward in Eden Township (T. 36 N., R. 8 E.).

OUTWASH.

A narrow strip of sandy and gravelly outwash appears along the outer border of the main moraine in the vicinity of Middlebury, and a tract of several square miles in the central and northern parts of Middlebury Township has so perfect an underground drainage that scarcely any surface drainage lines have been developed. In one place in section 8 drainage lines lead into a deep basin. There is also underground drainage in much of the "Haw patch" gravel plain at the southeastern end of the moraine. It is probable that the glacial drainage from the part of the moraine near Middlebury passed through a series of marshy channels leading westward from the central part of Middlebury Township to the Canal Marsh channel.

Between the main moraine and the inner ridge there is a swamp underlain with sand, through which a State ditch has been carried to improve the drainage. This swamp seems to have been a line of glacial drainage for water escaping from the Huron-Erie lobe after the Saginaw lobe had withdrawn from the weak moraine that lies east of it.

Little Elkhart River flows along the eastern edge of its valley and cuts in places into the weak moraine, indicating that the valley did not receive much outwash from the moraine, for otherwise the stream would have been thrown toward the west bluff. This valley, like the one drained by the State ditch, was probably utilized by later glacial drainage than that connected with the moraine which borders it. There is an extensive gravel plain outside of the Lagrange moraine in the headwater part of Little Elkhart River that opens into and in all probability discharged its waters down the Little Elkhart Valley. Some erosion seems to have occurred as a result of this glacial drainage, for the broad valley of the stream shows definite trenching, though its bluffs are low.

The features of the St. Joseph Valley opposite the end of the Middlebury moraine (p. 142) are such as characterize an ice border and it is probable that the St. Joseph was at one time the principal line of direct discharge from the Saginaw lobe, as well as the line of indirect discharge from tributary valleys. This might have been the case even if the Lake Michigan lobe overhung much of the plain along the river.

INNER BORDER.

Two narrow strips of till plain lie east of the inner ridge in the southwestern part of Lagrange County, one being north of Little Elkhart River and the other south. The one to the north has an area of about 12 square miles and is 2½ to 3 miles wide. It fills the space between the inner Middlebury moraine and the Lagrange moraine. Its till is rather loose textured, with some gravel and sand beds. The till strip to the south is scarcely 2 miles wide; it leads southeastward between the "Haw patch" gravel plain and the gravel plain on the headwaters of Little Elkhart River to a moraine of the Erie lobe in southern Lagrange County. It has a more clayey till than that in the strip north of the Little Elkhart.

The gravel plain which lies between these till plains, like the gravel plains to the north and south, are dependencies of the Lagrange moraine. (See p. 145.)

LAGRANGE MORAINE.

COURSE AND DISTRIBUTION.

The Lagrange moraine takes its name from the village of Lagrange, the county seat of Lagrange County, which stands at the junction of the Saginaw and the Huron-Erie lobes. From the village the Lagrange moraine leads northwestward, the correlative in the Huron-Erie lobe leads southwestward, and a short interlobate spur extends about 5 miles northeastward.

The Lagrange moraine runs west-northwestward from Lagrange about parallel with Pigeon River through southern Clay, northeastern Newberry, and southwestern Van Buren townships, Lagrange County, into the northeastern part of the northeast corner township of Elkhart County, where the St. Joseph River valley interrupts it for a few miles, though a pitted gravel plain fills much of the gap. It sets in again just north of the river in the southeast

corner of Cass County, Mich., and continues west-northwestward for about 12 miles to the valley of Christian Creek, about 5 miles southeast of Cassopolis, west of which it disappears, giving place to an outwash apron from the Kalamazoo morainic system of the Lake Michigan lobe.

Southwest from Lagrange what appears to be the Huron-Erie equivalent of the Lagrange moraine is distinctly developed in the district between Lagrange and Elkhart River. It leads southwestward from Lagrange to Ligonier, passing just east of Topeka, and bears away southeastward to Albion, where it merges with the great moraine of the Huron-Erie lobe. (See p. 158.)

The Lagrange moraine is about 3 miles wide, though somewhat broader at its northwestern end. The correlated moraine in the Huron-Erie lobe is 2 to 3 miles wide.

TOPOGRAPHY.

In its greater part the moraine rises above 900 feet and at a few points it exceeds 1,000 feet; much of it reaches between 900 and 950 feet. One elevation of about 1,000 feet is a knob in the northeast corner of Elkhart County, Ind., on the line of secs. 13 and 24, T. 38 N., R. 7 E.; another is the knoll bearing the Calvin geodetic station, in southern Cass County, Mich., whose altitude is 1,011 feet; a third is a ridge east of Lagrange in secs. 14, 15, 22, 23, 26, 27, T. 37 N., R. 10 E. In Indiana the relief above the outer border district is very slight, averaging scarcely 20 feet; above the inner border it is much greater, because of the Pigeon Valley depression. It is least near Lagrange, where it is fully 75 feet, increasing westward to more than 100 feet. In Michigan the relief above the outer border is only 25 to 50 feet except in a small district around the Calvin geodetic station, where it exceeds 100 feet. The relief on the inner border is somewhat less than it is on the outer.

The Indiana portion of the Lagrange moraine contains numerous small steep-sided knolls, among which are marshes and gently undulating till tracts. Several square miles in the northwest part of Lagrange County and the northeast part of Elkhart County have sharp knob and basin topography, in which knobs 40 to 60 feet high inclose tamarack swamps and small lakes without outlet. East of Lagrange a prominent ridge in secs. 10, 11, 14, 15, 22, 23, 26, and 27, T. 37 N., R. 10 E., stands 50 to 75 feet or more above a plain east of it and 25 to 50 feet above the bordering moraine on the west.

The portion in Michigan sets in near the State line with sharp knolls between Baldwins Lake and Long Lake. A fosse or depression, 20 to 30 feet below the gravel plain south of it and one-eighth to one-fourth mile wide, is present along much of the outer border from Long Lake to Christian Creek. The main ridge lies 1 to 2 miles or more back from the southern edge of the moraine, and diverges from it somewhat, trending slightly north of east across Calvin Township from sec. 30 to sec. 24, whereas the south border of the moraine trends south of east from sec. 31, Calvin Township, to Long Lake in sec. 9, Union Township. The district between the fosse and the main ridge is gently undulating and is thickly strewn with bowlders. The main ridge bears a chain of sharp gravelly knolls, which rise 50 feet or more above the general level; it is on one of these that the Calvin geodetic station was placed. North of the main ridge a chain of lakes leads from secs. 13 and 24 westward to Christian Creek. They are bordered closely by sharp knolls and ridges and have no broad outlets nor connecting strips of lowland. North of the chain of lakes in secs. 10, 11, 13, 14, 15, and 16, Calvin Township, is a gently undulating tract thickly strewn with bowlders which gives place farther north and west to a gravelly plain. The portion in Cass County, Mich., seems to have been formed in a reentrant between the Lake Michigan and Saginaw lobes. The strong ridge on which the Calvin geodetic station stood has the trend natural to the Lake Michigan lobe.

STRUCTURE OF THE DRIFT.

Most of the sharp knolls are composed of gravel even where the surface of the gently undulating moraine around them is clayey till. The knob and basin tracts are composed of gravel, cobblestones, and bowlders, with only a small amount of till or assorted material. Bowlders

are conspicuous on the gently undulating as well as on the rough parts of the moraine in both Indiana and Michigan. Considerable sand and gravel seem to be associated with even the most clayey parts of the moraine, for strong wells are generally obtained at moderate depths.

Four records of waterworks wells at Lagrange, all within the area of a town lot, are presented by Dryer[1] to show the great differences in structure. He remarks that the majority of beds can not be correlated in any two of them. Dryer also calls attention to the occurrence of coal fragments in the drift of western Lagrange County (the part covered by the Saginaw lobe), but this is not surprising as the Saginaw lobe passed across the Michigan coal basin to reach Lagrange County, Ind.

The depth to rock is known at very few points in this region and where known indicates a large amount of drift. In Lagrange County several wells go down about 200 feet without reaching bedrock and but one well has been recorded as striking it. This was a farm well in the southwest part of the county outside the limits of the Lagrange moraine; the record was obtained by Dryer, who merely reports that "black slate" was struck at 150 feet.

A prospect boring for artesian water at the county jail in Lagrange reached a depth of 205 feet without entering rock or obtaining a flow. It possesses interest, however, from the reported occurrence, at a depth of 65 feet, of a soil bed which may mark the division line between the Wisconsin and the pre-Wisconsin drift. A well about 4 miles south of Lagrange on the farm of Dr. Drake is also reported to have penetrated a buried soil. The records of the borings are as follows:

Record of prospect boring at Lagrange jail.

	Feet.
Till, yellow	15
Till, blue, with thin beds of sand	50
Mold or soil, brown (Sangamon?)	4
Gravel, cemented	5
Gravel, loose, with water	8
Till, blue (Illinoian?)	45
Gravel, cemented	8
Sand and gravel, dry, or sandy till	70
	205

Record of Drake well near Lagrange.

	Feet.
Till, sandy, yellow	10
Till, blue	41
Gravel with inflammable gas	3
Clay, blue (till?)	46
Muck, black, with leaves and gas	6
Clay, soft, blue; no pebbles noted	24
Sand, water-bearing, coarse near bottom	10
	140

On the sharp ridge about 4 miles east of Lagrange a well 202 feet in depth, largely through till, struck no rock and failed to obtain water. On the same ridge another well obtained water under a thick bed of till at 175 feet. Much of the ridge has a gravelly, cobbly surface; its north end is sandy.

On the Michigan part of the moraine many wells are sunk 75 feet or more before entering water-bearing sand or gravel; some of them pass through considerable dry sand. The water table is naturally low on account of the height of the moraine and the loose texture of the drift.

OUTWASH.

A gravelly and sandy outwash plain extends along the entire outer border of the Lagrange moraine except for about 3 miles in western Clay and eastern Newberry townships, Lagrange County, 5 to 8 miles west of Lagrange, where it gives place to a till plain.

An outwash apron in the reentrant angle between the Saginaw and Huron-Erie lobes southwest of Lagrange appears to have been built principally from the Huron-Erie lobe, for its gravel is much coarser on the side of the Huron-Erie lobe than it is on the side of the Saginaw lobe. Moreover, the slope away from the Huron-Erie lobe is the more rapid. The Saginaw lobe appears to have simply held its ground north of the gravel plain while the Huron-Erie lobe built up a large outwash apron. Gravel overspreads the southern tier of sections in Clay Township (T. 37 N., R. 9 E.) and about 12 square miles in the northwestern part of Clear

[1] Eighteenth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1893, pp. 80-81.

Spring Township (T. 36 N., R. 9 E.), and a strip of gravel 1½ to 2½ miles wide leads westward from these townships down Little Elkhart River. On the north edge next to the Saginaw lobe there are marshy bowlder-strewn depressions, which were probably occupied by the ice while the outwash plain was receiving its coating of gravel.

In northern Newberry Township and westward to the St. Joseph Valley an outwash plain of sandy gravel about 2 miles wide borders the Lagrange moraine. The western portion in the vicinity of St. Joseph River is somewhat cobbly. It contains several lakes among which Shipshewanna, Mud, Cass, East, and Hunters lakes are sufficiently large to receive names; the largest is Shipshewanna Lake with an area of about 200 acres and a depth of only 8 to 14 feet. In northeastern Elkhart County, between Hunters Lake and the St. Joseph Valley, the plain is trenched by ravines, some of which have been cut down 25 or 30 feet to the underlying till. This part of the plain has an altitude of about 875 feet. It stands nearly 50 feet above a lower plain on the Little Elkhart that leads in from the gravel plain in the reentrant angle southwest of Lagrange. This indicates that the Huron-Erie lobe was furnishing a strong line of drainage down to a time later than that of the most vigorous outwash from the Saginaw lobe.

On the outer border of the part of this moraine in Cass County, Mich., a gravel plain, indented with small basins and evidently built as an outwash from the ice, slopes rapidly southward toward the St. Joseph Valley, dropping from fully 850 feet at its northern edge to below 800 feet within 5 miles south. The conspicuous fosse (p. 144) that lies along its north edge for several miles east from Christian Creek seems to have been occupied by the ice sheet while the outwash plain was forming. Along the south border of the fosse the material is very coarse, with stones several inches in diameter mixed with the gravel, but it changes rapidly to finer material southward. Gravel is found, however, clear down to St. Joseph River opposite Bristol and thence westward about to a group of lakes in the northeast part of T. 38 N., R. 5 E. Farther west and south there is sand. The lakes, some of which are 200 acres or more in extent, are so shallow that cattle can wade all over them.

INNER BORDER.

There is but little space between the Lagrange moraine and the gravel plain of Pigeon River in Lagrange County, and that little is filled in part with sandy deposits and in part with a gently undulating loose-textured till interrupted by many marshy tracts that extend back from the river. The topography was probably developed in the course of the northward recession of the ice border. In Elkhart County the moraine is bordered on the north by the great gravel plain of St. Joseph River. In Cass County, Mich., a gently undulating plain of rather compact clayey till on the northeast border covers much of T. 7 S., R. 13 W. Numerous small lakes occur in this till tract. On the north and east the till gives place to sandy drift, probably connected with the next later moraine, the Sturgis.

STURGIS MORAINE.

COURSE AND DISTRIBUTION.

The Sturgis, a prominent moraine of the Saginaw lobe and of the reentrant between the Saginaw and Lake Michigan lobes, is named from the village of Sturgis, which stands at its outer edge in southeastern St. Joseph County, Mich. It lies chiefly in southern Michigan but enters Indiana slightly and connects with a morainic belt of corresponding age formed by the Huron-Erie lobe. It is greatly interrupted by lines of glacial drainage which head in later moraines and cut through it, producing gaps 1 to 6 miles in width.

West of Three Rivers, Mich., the Sturgis moraine runs into a great interlobate tract, which covers much of Fabius and Flowerfield townships, St. Joseph County, and of Newburg and southeastern Marcellus townships, Cass County, and which terminates on the south near the Michigan Central Railroad from Vandalia to Three Rivers. The greater part of this tract is shown by the distribution of outwash aprons to have been formed by the Lake Michigan lobe. However, part of it is occupied by a moraine of the Saginaw lobe running southeast

from Corey Lake near Fabius to St. Joseph River. Its inner border is at Pleasant Lake in secs. 3 and 10, Fabius Township. An outwash north of Pleasant Lake in secs. 3 and 10, Fabius, and sec. 34, Flowerfield, connects with a strong moraine of the Lake Michigan lobe lying west of it.

The great gravel plain that leads down St. Joseph River passes through this moraine in a gap 5 or 6 miles wide. East of this gravel plain and immediately south of Centerville the main ridge of the Sturgis moraine sets in and bears southeastward into Indiana, passing between Sturgis and Burr Oak, Mich., and just north of Lexington and Orland, Ind. In St. Joseph County, Mich., it has a width of 3 to 6 miles, but in Branch County, Mich., and in Lagrange County, Ind., it is somewhat narrower and is more or less separable into distinct ridges with intervening gravel plains. It connects with a strong moraine of the Huron-Erie lobe about 2 miles east of Orland in the north part of the northwest corner township of Steuben County, Ind. Outside of it, a weaker moraine of the Huron-Erie lobe connects with the Sturgis moraine about 2 miles west of the Steuben-Lagrange county line.

More or less isolated tracts on the inner border of the main moraine seem to be properly included with the Sturgis moraine. One tract about 5 square miles lies north of Centerville and is surrounded by the gravel plain of St. Joseph River. Another tract about 8 square miles, also surrounded by the same gravel plain, lies along the Michigan Central Railroad from Wasepi to Fairfax. A small sharply morainic tract north of Mendon on the north side of the gravel plain of St. Joseph River and other sharply morainic tracts east and south of Colon on the south side of the river seem also to belong to this moraine. Indeed, the country northeastward from the main part of the Sturgis moraine constitutes a transition belt several miles wide, in which a change from sharply morainic to nearly plane topography occurs. Northeastern St. Joseph and southeastern Kalamazoo counties embrace such a district on the north side of St. Joseph River, and western Branch County carries its continuation on the south side.

If all these isolated morainic tracts and the transition belt are thrown in with the Sturgis moraine it has a width of nearly 20 miles. Its outer border is very definitely determined by a great outwash plain that fits about it all the way from St. Joseph River to the junction with the morainic belt of the Huron-Erie lobes, and shows the trend of the ice border. The inner border, with its transition belt and long spurs reaching back into the bordering till plain, makes a striking contrast to the very regular outer border. The glacial map (Pl. VII) makes clear the position and relations of the various parts of the moraine and shows its relation to the moraines of the Lake Michigan and the Huron-Erie lobes.

TOPOGRAPHY.

ALTITUDE.

The altitude of the greater part of the Sturgis moraine is between 900 and 1,000 feet and is nowhere much below 900 feet. In several places it rises above 1,000 feet and in one place it appears, by barometric determination, slightly to exceed 1,100 feet. The altitude of this apparent highest point, which is in the Lake Michigan part of the interlobate tract in the central part of Newberg Township, Cass County, was determined by W. F. Cooper to be 1,115 feet. The altitude of another knoll a mile west is 1,070 feet. These knolls rise more than 100 feet above the surrounding country, there being probably less than 2 square miles in Newberg Township above the 1,000-foot contour. A single knoll in southern Flowerfield Township, St. Joseph County, also on the Lake Michigan part, was found by Cooper to rise above 1,000 feet. A small area around the Sherman geodetic station, 4 miles northwest of Sturgis, rises above 1,000 feet, the hill on which the station stood being 1,038 feet. The altitude of the southeastern end of the main part of the moraine in northeastern Lagrange and northeastern Steuben counties, Ind., and of a part of its outwash apron slightly exceeds 1,000 feet. The lowest part of the moraine is on the borders of the St. Joseph Valley in central and eastern St. Joseph County, and this is not less than 850 feet, except perhaps in basins and sags among the knolls.

The outer border plain or outwash apron, where not trenched by later glacial drainage, stands nearly as high as the moraine. Its greatest height, 1,000 to 1,010 feet, is in northeastern Lagrange County, Ind., and it shows a steady decline to the westward along the edge of the moraine, being 935 at Sturgis, 890 opposite Klinger Lake, and 820 feet near White Pigeon. Its height, in the portion west of St. Joseph River near Fabius, on the outwash from the Saginaw part of the interlobate tract, is about 900 feet; on the outwash apron east of the moraine of the Lake Michigan lobe in sec. 34, Flowerfield Township, St. Joseph County, it is also about 900 feet.

The general relief of the moraine above the outwash aprons in the district west of St. Joseph River is only 30 to 50 feet, though as above indicated the highest knolls are about 200 feet higher. In the district southeast of the St. Joseph the relief is not generally more than 30 feet, but the knolls near the Sherman geodetic station reach about 100 feet above the neighboring part of the outwash apron.

On part of the inner border of the main portion of the moraine the gravel plain is somewhat lower than it is on the outer border which sweeps around the island-like tracts of moraine above noted. Its altitude near Centerville is 820 to 830 feet, but it rises southeastward to about 875 feet near Burr Oak. The adjacent parts of the moraine are 75 to 100 feet higher than the plain. The island-like tracts rise 25 to 100 feet above the plain, the most prominent being "Colon Mountain" just south of Fairfax station, which rises fully 100 feet above the bordering plain, or about 950 feet above sea level. The narrow strips of gravel plain between the morainic ridges southeast from Sturgis are somewhat lower than the outwash apron outside and become lower and lower from south to north. The inner slopes of these ridges consequently show more relief than the outer ones.

CHARACTER.

The topography of the main part of the moraine is largely of the knob and basin type, most of the knolls have steep slopes. The portion near Sturgis and westward to Centerville is so rough that many steep grades are necessary on the Grand Rapids & Indiana Railway and on the numerous wagon roads that cross it. The railroad profile shows altitudes ranging from 877 to 957 feet within the limits of the moraine; barometric readings along a north-south road from Centerville across the moraine, taken by Cooper, show a range from 823 to 942 feet between the lowest basins and the highest ridges or knolls crossed by it; the main road east from Sturgis across the moraine shows a range from 895 up to 954 feet, the altitude of the edge of the outer border plain being 937 feet.

Numerous basins in the midst of the moraine from the meridian of Sherman westward to the gravel plain of St. Joseph River are much lower than the outwash apron south of the moraine. Klingers Lake and the chain of lakes east of it have a water surface 50 to 60 feet lower and beds in places fully 100 feet lower than the part of the outwash apron immediately south of them. The surface in this part of the moraine thus ranges from about 100 feet above (at the Sherman geodetic station) to 100 feet below the outwash apron.

Southeast from Sturgis the moraine shows less roughness of topography than it does northwest of that place, much of the surface between ridges being graded up with gravel and sand to a plain. The outer ridge is practically continuous for about 14 miles from Sturgis to a point within 2 miles of Orland and yet in places is less than one-fourth mile wide and scarcely anywhere is a mile wide. The ridges back of it are interrupted by many gaps and more than half its surface is occupied by sandy plains.

Most of the knolls north of the main ridge near Centerville and east of Wasepi are small, but a few are 50 feet high, and, as above noted, Colon Mountain stands 100 feet above the bordering plains.

The district north of Mendon is similar to the knolly tracts, except that it fades gradually into a till plain toward the northeast.

In western Branch County the inner part of the Sturgis moraine is characterized by strips of sharply undulating or ridged drift alternating with nearly plane strips, all trending northeast

and southwest directly toward the main part of the moraine instead of parallel with it. Some of the ridges are continuous for 3 to 4 miles and are loosely connected end to end for 10 to 12 miles. They rise 20 to 40 feet and in places 60 feet above the bordering nearly plane tracts. One of the most prominent, located 2 miles west of Bronson, was used as a site for a geodetic station. It has an altitude of 998 feet above sea level and is bordered by a plain whose altitude is 910 feet on the south and about 920 feet on the north. It forms the southwestern terminus of a narrow ridge about 3 miles in length.

In addition to the ridges and till plains this district, in western Branch County, is traversed by gravel plains that also trend northeast and southwest or parallel with the ridges. One of these gravel plains heads about 4 miles east of Colon and gradually expands westward to enter the gravel plain of St. Joseph River at Colon. South of this and separated from it by a ridged belt scarcely a mile in width is a longer and larger gravel plain that heads east of Matteson Lake and includes the lake. A still larger gravel plain (2 to 4 miles wide) leading from Coldwater River southwestward to Prairie River may have received an outwash from the moraine of the Huron-Erie lobes on the east as well as from the receding Saginaw lobe.

It is probable that all these drainage lines as well as the great gravel plain on the St. Joseph extended headward with the retreat of the ice sheet. The smaller two seem to have ceased to be functional before the ice had withdrawn, and the larger two to have remained in operation. Whether the elongated ridges were formed by gradual extension from southwest to northeast with the recession of the ice is not so clear. Indeed, their method of development is not as yet understood.

In the southern part of Branch County the ridges and knolls are distributed more irregularly than they are in the western part and they inclose gravelly and sandy plains as well as till plains. They commonly rise 20 to 30 feet above the plains and are either isolated or in small groups.

West of Three Rivers, in the prominent interlobate part of the Sturgis moraine, much very rough land is interspersed with basins occupied by lakes and marshes. Spurs of moraine run out into the lake basins and sharp knolls appear in the midst of the basins. The high knobs in central Newberg and southern Flowerfield townships are among the most prominent in southern Michigan. A strip on the northwestern edge of the tract that includes these sharp knobs is more choppy than the remainder of the moraine, possibly owing to overriding by the Lake Michigan lobe after the melting of the Saginaw lobe. (See p. 152.)

STRUCTURE OF THE DRIFT.

CHARACTER.

The surface of the Sturgis moraine is almost everywhere thickly strewn with bowlders. This is true not only of the main part of the moraine but also of the isolated or island-like tracts and of the transition belts on the inner border. The bowlders number several thousand to the square mile and are of various sizes up to 10 or 12 feet or more in diameter. Their presence in such numbers intensifies the morainic expression even of a belt whose knob and basin topography is strongly morainic. The bowlders, which include numerous quartzites and some quartzitic conglomerates apparently from the Huronian formations north of Georgian Bay, are chiefly of granite, as in moraines farther south and west.

The sharp knolls and ridges of the moraine also carry a large amount of surficial cobbly material, and the numerous shallow cuts and gravel pits indicate that considerable water action attended their deposition. The beds show many interruptions and changes of dip and more or less disturbance. The amount of clayey till is very small, at least in the upper part of the drift, and there appear to be many changes both horizontally and in vertical section from loose-textured till to assorted beds of gravel and sand and back again. Few wells go down more than 60 feet and most of them only 20 to 40 feet, so the knowledge of the deeper part of the drift is very meager.

In the transition belt, on the inner border of the moraine, till of clayey texture is the prevalent deposit both on the ridges and on the intervening till plains. Some of the sharpest ridges and knolls, however, contain assorted material either in pockets or in beds.

THICKNESS.

Depth to rock.—Rock has been struck in deep wells at White Pigeon and Constantine south of this moraine and may have been reached in the waterworks well at Three Rivers. At White Pigeon the distance to rock is at least 182 and possibly 240 feet, there being a record of sand under so-called shale at 212 to 240 feet from the surface that leads to the suspicion that the "shale" is hard till; there is 140 feet of sand and gravel before reaching any till. At Constantine the drift is 136 feet thick, and at Three Rivers it may not exceed 100 feet. The wells at all these places are on ground whose altitude is about 800 feet. The altitude of the rock surface is, therefore, only 700 feet at Three Rivers and is considerably less at the other two villages. If this low altitude is maintained beneath the high part of the Sturgis moraine, as seems probable, there is possibly about 400 feet of drift in and beneath the highest knolls. The deepest recorded boring on the high tract in Newberg Township, Cass County, is in sec. 21, where 199 feet was penetrated and no rock was struck. Several wells in this and neighboring sections are over 100 feet deep, and W. F. Cooper estimates the average depth of wells for the township to be 97 feet. The amount of drift in this region can be roughly estimated by comparing the map of rock contours (Pl. II) with the surface contour lines of the topographic map (Pl. I).

Well data.—At Sturgis the waterworks wells have been sunk 140 feet without reaching rock and are thought by the superintendent to have been largely through sand and gravel.

Wells on the borders of Klingers Lake have artesian head about 20 feet above lake level and many of them flow. They range in depth from 20 to 80 feet, passing through layers of hardpan or cemented gravel and perhaps some till.

In the transition belt in western Branch County most of the wells are 20 to 40 feet deep, though a few tubular wells reached depths of 75 to 100 feet, largely through clayey till. The deepest wells are on the ridges.

In southeastern Kalamazoo County on the undulating till tract near Fulton one boring reached a depth of 275 feet without striking rock or obtaining water. It is reported to have been entirely through a clayey till, which apparently forms a more continuous sheet than it does in the districts south of St. Joseph River.

OUTWASH.

The principal outwash connected with the Sturgis moraine lies on the outer border of the main part of the moraine, but, as already indicated, small outwash plains lie between the constituent ridges in St. Joseph and southwestern Branch counties, and outwash plains are also developed in the transition belt along the inner border.

Outside of the moraine a gravel plain about 6 miles in average width and in places 10 miles in width is traversed for its entire length by Pigeon River. It is doubtful, however, if the outwash from the Sturgis moraine was carried south of the river, the deposit on that side being more probably formed as the ice border receded down the slope from the Lagrange moraine to the river. A portion of the plain north of the river may also have been built up during the recession to the position held by the Sturgis moraine. This interpretation is supported by numerous basins far out in the gravel plain and by the presence of considerable coarse material at distances to which it could scarcely have been carried by direct discharge from the moraine.

The possibility of submarginal deposition of some of the gravel and sand should also be considered, for in places a coating of bowldery material has apparently been let down by the melting of the overhanging ice. Such material is especially noticeable in northeastern Lagrange County in a reentrant between the Saginaw and Huron-Erie lobes east of a line running from Lexington to Mongo.

Generally speaking, the coarsest material lies in a narrow strip along the front of the moraine, and within 2 miles from the edge it has given place to sand or very fine gravel. The descent

of the plain appears to be more rapid directly away from the moraine southward than along the moraine westward, though it is rather rapid in the latter direction.

Wells, reported to be through sand and gravel, have penetrated the highest part of the gravel plain near Lexington and Mongo, Ind., to depths of 70 or 80 feet before reaching the water table. At White Pigeon, Mich., fine sandy gravel was found to a depth of 140 feet, and at Sturgis the waterworks wells appear to have been through gravel and sand to a depth of 140 feet. So far as can be learned all the material is loose or uncemented and seems likely to have been deposited in the Wisconsin stage of glaciation and perhaps in large part immediately preceding and accompanying the development of the Sturgis moraine.

The topography along the south border of the Sturgis moraine is more diversified on the west side of the St. Joseph Valley than it is on the east side. In the vicinity of Fabius are characteristic outwash features in the form of a pitted gravel plain. South of this, in southern Fabius and northern Constantine townships, St. Joseph County, are sandy undulating tracts whose structure is what might be expected in an outwash apron, but whose surface is more rolling than in the ordinary outwash apron; they include knolls as well as basins, but show few bowlders or coarse pebbles. West of this for a few miles in the eastern edge of Cass County there is no definite outwash, the moraine being bordered by a gently undulating till tract. But in southwestern Newberg Township sandy drift sets in along the south border of the moraine and extends west past Vandalia to the gravel plain that borders the Kalamazoo morainic system of the Lake Michigan lobe. This sandy district, which includes several lakes and is much interrupted by basins and marshes, may have been produced during the retreat of the ice across it instead of as an outwash from the Sturgis moraine. The same is true of the undulating sandy tract in Constantine and Fabius townships. The outwash on the east side of the moraine of the Lake Michigan lobe in secs. 3 and 10, Fabius Township, and sec. 34, Flowerfield Township, seems to have been deposited among stagnant parts of the ice sheet, for it is interrupted by many basins.

The strips of gravel plain between the constituent ridges of the Sturgis moraine in southeastern St. Joseph and southwestern Branch counties have rapid variations from coarse to fine material, some portions being cobbly while others near by are sandy. On the whole, however, the sandiness increases from Branch County northwestward toward the St. Joseph Valley through southeastern St. Joseph County along the course of discharge of the glacial waters. The gravel plains that extend up into the transition belt in western Branch County have a moderately coarse gravel with perhaps less admixture of sand than the plain with which they connect in eastern St. Joseph County. At the eastern or headward ends, however, the material seems to have been somewhat irregularly and indefinitely assorted by stream action. In places it is difficult to determine where the gravel has its head, the passage from the till into the gravel being apparently gradual rather than abrupt.

INNER BORDER.

Attention has already been directed to the gradual change from moraine to till plain and to the extension of morainic spurs back into the till plain to the inner border of the Sturgis moraine (p. 147). In southeastern Kalamazoo and southwestern Calhoun counties an area of about 100 square miles is composed of clayey till and has a gently undulating surface, knolls 10 to 20 feet high being numerous. It is strewn with bowlders liberally but not so heavily as the bordering moraines. This till tract is limited by the Tekonsha moraine on the northeast, by the Sturgis moraine near Mendon on the southwest, by a gravel plain known as Climax Prairie (formed in connection with the Tekonsha moraine) on the north, and by the great gravel plain of the St. Joseph River valley on the south.

South of the St. Joseph plain, in northern and central Branch County, an undulating till tract similar to that north of the gravel plain is traversed by Coldwater River from Coldwater to Union City. West of the Coldwater the tract is interspersed with the till ridges and knolls of the transition belt already discussed (p. 147). East of the river the tract has a gently undulating surface with few noteworthy knolls.

The altitude declines markedly westward across the district, being 1,025 to 1,060 feet above sea level near the border of the Tekonsha moraine, about 980 feet at the bluff of Coldwater River, and about 920 feet on the meridian of Bronson (disregarding the knolls). The drift is largely clayey till with a very few gravelly knolls. Bowlders are everywhere numerous.

TEKONSHA MORAINE.

COURSE AND DISTRIBUTION.

The name Tekonsha is applied to a comparatively strong moraine of the Saginaw lobe which sets in at Quincy, Mich., runs northward rather weakly to the St. Joseph Valley, in which it occupies a great bend, and is thence strongly developed westward to the village of Tekonsha, Calhoun County. Here it crosses the St. Joseph Valley, leads northwestward across the southwestern part of Calhoun County, and comes to the Kalamazoo Valley near the line of Calhoun and Kalamazoo counties. It has a general width of 4 to 5 miles but is in places much narrower. As interpreted, the moraine finds continuation northward from the junction of the Saginaw and Lake Michigan lobes. This spur, however, is developed only from the river northward about 6 miles to the border of a later moraine of the Saginaw lobe that follows the north side of the Kalamazoo Valley.

The moraine is reduced to a remarkably narrow strip in its passage across the Nottawa Creek valley northwest of Burlington for 3 to 4 miles, being scarcely one-half mile wide. It is similarly reduced along the south bluff of St. Joseph River for 3 miles west from Tekonsha. In each place a gravel outwash apron fits about the southern edge of the moraine and by its contrast helps to give the hummocky, bowldery morainic strip strong expression despite its narrowness.

Correlative moraines of the Lake Michigan lobe and of the Huron-Erie lobe connect with the Tekonsha moraine at its northwestern and southeastern ends respectively.

The correlative moraine of the Lake Michigan lobe, which occupies a belt about 3 miles wide on the south side of the Kalamazoo Valley, is well developed for 7 or 8 miles southwest from its junction with the Tekonsha moraine, and is then cut off by a great gravel plain that heads in moraines north of Kalamazoo River and runs southward through central Kalamazoo County. Beyond this plain its continuation is doubtful, though a bowldery strip was traced from the end of the moraine as far as the north end of Long Lake or half way across the gap. The connection may be found in a sharply ridged tract that sets in near the south edge of the southwest township of Kalamazoo County about 3 miles southwest of Schoolcraft and runs southward to Rock River at Howardsville, beyond which to the vicinity of Vandalia it overrides or forms the western edge of the sharply morainic tract in eastern Cass and western St. Joseph counties. (See p. 149.)

The correlative moraine of the Huron-Erie lobe, which connects with the Tekonsha moraine near Quincy, Mich., is rather vaguely developed, but apparently embraces an undulatory belt that leads westward and southward to the State line just east of Orland, Ind. It may also include undulating tracts south of Quincy, in Quincy and Alagansee townships, Branch County, Mich. The portion south of the State line is so closely combined with other moraines of the Huron-Erie lobe that separate description can scarcely be given it and the entire system is considered together in another section. (See pp. 148–149.)

TOPOGRAPHY.

ALTITUDE AND RELIEF.

From Quincy to Tekonsha the altitude of the Tekonsha moraine drops from about 1,100 to 1,000 feet. Beyond Tekonsha a small area at the north bluff of the St. Joseph, 2 miles to the west, has an altitude of 1,075 feet, and another small area 2 to 4 miles to the northeast rises above 1,000 feet, but the greater part of the moraine south of Kalamazoo River is between 925 and 975 feet. North of the Kalamazoo the interlobate spur is not far from 900 feet in

general elevation. It stands but little higher than the bordering gravel plain, and its sags and sloughs are lower than the gravel plain.

The general relief of the moraine above the outer border district is only 20 to 30 feet, though that of individual knolls or groups of knolls is 100 feet. The relief of the inner border between St. Joseph and Kalamazoo rivers is about the same as that of the outer, though a little greater near the Kalamazoo and a little less near the St. Joseph. For part of its course the crest of the moraine forms the divide between tributaries of the St. Joseph and those of the Kalamazoo.

CHARACTER.

On the whole the Tekonsha moraine has not so rough a surface as the Sturgis moraine. Many of its knolls are but 10 to 15 feet high and few exceed 40 feet. It is, however, exceptionally prominent in two places; one, in western Tekonsha Township, is locally known as "the Alps" and has knolls 80 to 100 feet high with very steep slopes; the other, in the reentrant on the south side of Kalamazoo River near the line of Kalamazoo and Calhoun counties, is known as "Tobys Hill" and rises more than 100 feet above neighboring districts on the east, north, and west.

In places peat bogs and basins are conspicuous. On the south side of St. Joseph River, immediately east of Tekonsha, 2 or 3 square miles is rendered largely waste land by the presence of boggy basins. Small knolls rise like islands from the boggy tract and a prominent part of the moraine sweeps around its eastern and southern edges. This prominent part of the moraine also includes boggy basins in the southwest part of Clarendon Township. Between Nottawa Creek valley and Kalamazoo River several small lakes are inclosed by morainic knolls, and others lie in gravel plains on the inner border of the moraine. Lakes are especially conspicuous from Quincy southwestward in the correlative moraine of the Huron-Erie lobe, Marble Lake and Coldwater Lake each having an area of more than 2 square miles, and several others having areas of one-fourth to three-fourths of a square mile. They are distributed in a chain which perhaps marks the line of a preglacial valley extending from near Quincy south-southwestward into Indiana.

The interlobate spur north of the Kalamazoo Valley is more conspicuous by reason of its depressions and basins than by its knolls and ridges. Some of the depressions are 30 to 50 feet below the bordering gravel plains; they seem to indicate that stagnant ice persisted here during the building of the gravel plains by outwash from a later moraine.

The correlative in the Lake Michigan lobe west of the reentrant angle in eastern Kalamazoo County has a very hummocky topography and incloses small lakes and basins. In roughness it is scarcely excelled by any part of the Tekonsha moraine unless it be "the Alps" west of Tekonsha.

GLACIAL DRAINAGE CHANNELS.

The moraine is interrupted by several valley-like gaps where glacial drainage seems to have been forced across it while the ice sheet was standing near its inner edge. The most conspicuous of these interruptions is a low gravel plain over 2 miles in average width immediately north of Tekonsha. South of the St. Joseph two narrow gaps only one-fourth to one-half mile wide cross the moraine east of Tekonsha in Clarendon Township. Between them is a narrow strip of moraine on which Clarendon Center stands. The channels unite near the Branch County line and the single valley continues southwestward emerging from the moraine about 2 miles northeast of Girard in secs. 11 and 12, T. 5 S., R. 6 W. A few miles farther south another channel leads across the moraine from St. Joseph River to Hog Creek, passing just north of the hamlet of South Butler. Between South Butler and Quincy a network of channels occupies more than half the surface, above which morainic knolls rise in small groups. A portion of the glacial drainage seems to have discharged from Quincy westward past Coldwater, and a portion northwestward past Girard along the Hog Creek valley to Coldwater River. These channels follow lines where the moraine was especially weak and where passages could therefore be easily opened.

STRUCTURE OF THE DRIFT.

COMPOSITION.

The drift of the Tekonsha moraine is generally loose textured even where not assorted. The looseness naturally results from the presence of much sand derived from the underlying or neighboring sandstone formations, as well as from the action of water and the removal of finer material during deposition. The nearest approach to clayey till noted is in western Calhoun County, a few miles south and southwest of Battle Creek, where the moraine laps upon a clayey plain that extends into eastern Kalamazoo County. The principal tracts of beech and maple timber are found here. There is ordinarily much diversity of structure within even small areas. On a single farm one well may be largely in sand or gravel, another in a loose-textured till, and a third in a combination of the till with sand and gravel. The interlobate spur north of Kalamazoo River is largely sand and gravel.

BOWLDERS.

Bowlders are very numerous over nearly the whole surface of the moraine and are also embedded in the drift, for nearly every cutting observed is full of them. They are least conspicuous on the interlobate spur north of Kalamazoo River. The bowlders are such an encumbrance that piles of them appear in nearly every field and several miles of fences are built of them. Places near Hog Creek in northeastern Branch County were estimated to carry 1,000 bowlders to the acre and some knolls in that vicinity are literally covered with them. Many of the bowlders are large enough to be shaped into building stone. The smaller ones are useful for checking the gullying of hillside slopes when thrown into ditches and are thus easily buried. The majority of the bowlders are well rounded, probably by exfoliation, and few show striated surfaces. As in the moraines to the southwest, granite rocks greatly predominate, but quartzites and quartzitic conglomerates abound and numerous other rocks are represented. Local sandstone in mass is rare on the surface, though blocks as well as small pieces abound within the drift sheet.

THICKNESS.

Relation to table-land of sandstone of the Marshall formation.—Compared with the drift in the district outside or southwest of the moraine, the drift of the Tekonsha moraine is very thin. This is due to the position of the moraine, which stands on the edge of the table-land of sandstone of the Marshall formation, whose rock surface is much higher than that of the adjacent lowland underlain by the Coldwater shale. The sandstone table-land has an altitude of 900 feet or more in Calhoun and eastern Branch counties, and some of its highest points exceed 1,000 feet. Accordingly, in numerous places along the moraine rock is struck at 50 feet or less, and in the district north of Quincy it stands above the level of some of the sags or channels in the moraine. The table-land is interrupted more or less by deeply eroded preglacial valleys that lead into the lowland to the southwest and at such places the drift must be very thick, presumably 200 feet or more, for much of the outlying lowland is at least 200 feet lower than the table-land. The table-land extends slightly into the eastern edge of Kalamazoo County south of the river near Climax but seems to be interrupted by a deep valley in the vicinity of the river. Borings in and near Augusta reach a level 100 feet below the present stream without encountering rock, one boring being 150 feet and another on higher ground 220 feet.

Well data.—The following record of one of the deep wells near Augusta was obtained from the driller. The well is on the Colchester farm on the northwestern outskirts of the village, at an altitude perhaps 120 feet above Kalamazoo River. Water rose within 70 feet of the surface.

Record of Colchester well near Augusta, Mich.

	Feet.
Gravelly or sandy material with thin beds or partings of clay	140
Clay, blue, rather compact (probably pre-Wisconsin)	80
Cement crust above water bed.	
	220

A well at the schoolhouse in Augusta on ground about 50 feet above Kalamazoo River was carried to a depth of 150 feet and passed through considerable blue till in its lower part. The till is struck beneath bordering gravel plains on the north side of Kalamazoo River and seems to be independent of and to antedate the moraine. Probably it is of pre-Wisconsin age.

The deepest well in the correlative moraine of the Lake Michigan lobe south of Kalamazoo River of which a record has been obtained is that of Mr. Schram, opposite Galesburg. It is on ground about 120 feet above the river and reached water at about 100 feet. The drift there is largely loose textured and gravelly.

A well on the Heritz farm east of Climax on ground about 975 feet above sea level is reported by the driller, S. Barlow, of Galesburg, to have struck sandstone at 47 feet and to have obtained a good supply of water at 50 feet. This seems to be near the western edge of the table-land of sandstone of the Marshall formation, for wells a mile west of the Heritz farm were sunk to a depth of 100 feet without reaching rock.

Records of two wells south of Tekonsha show a striking difference in drift structure as well as a large amount of drift. One at William Wagner's, on a sharp morainic knoll in sec. 3, Girard Township, is largely through till, part of it a stiff clay, and strikes rock at about 175 feet; its entire depth is 184 feet. Another on the outwash apron just outside the moraine, on the farm of J. W. Mitchell in sec. 33, Tekonsha Township, entered rock at 164 feet and reached a depth of 180 feet; it penetrated 45 feet of gravel, below which it was in quicksand to the rock. Both wells are on ground nearly 1,000 feet above sea level. Along the moraine northwest from the wells a thin sheet of bowldery, loose-textured till covers a thick deposit of sand, which is entered in some wells at 15 to 20 feet.

On a prominent knoll in sec. 22, Butler Township, Branch County, about 70 feet above the surrounding country or 1,075 feet above sea level, a well 107 feet deep enters rock at 90 feet, after penetrating considerable till under a surface deposit of gravel.

OUTWASH.

Except for a few miles in southwestern Calhoun County, where it laps upon a till plain, the Tekonsha moraine is bordered by well-defined outwash aprons or by lines of glacial drainage. The correlative moraine of the Lake Michigan lobe in eastern Kalamazoo County also is bordered by an outwash apron, and correlative in the Huron-Erie lobe in southern Branch County is deeply indented by gravelly aprons that extend back into it; the latter has a continuous belt of gravel on its outer border.

REENTRANT ANGLE.

The outwash in the reentrant angle between the Saginaw and Lake Michigan lobes in eastern Kalamazoo County shows a marked slope from northeast to southwest along the edge of the Lake Michigan correlative. The altitudes and slopes are well shown in the profile of the Grand Trunk Railway, which traverses it from northeast to southwest. The altitude is 990 feet at the northeast edge of the gravel plain, 976 feet at Climax, and 912 feet at Scott station, 6 miles southwest of Climax, giving a slope southwestward of about 10 feet to a mile. Gravel and cobble are plentiful at the northeast, but sand becomes conspicuous toward the southwest near Scott. Basins containing small lakes appear at the northeast but become inconspicuous toward the southwest. Some irregularity of surface in the southwestern part seems likely to be the result of glacial drainage rather than the work of modern streams.

The till plain south of the outwash apron extends to the outer border of the Tekonsha moraine near East Leroy.

GRAVEL PLAIN OF ST. JOSEPH VALLEY.

From the vicinity of East Leroy southeastward to the St. Joseph Valley, a distance of 10 miles, lies the head of the great gravel plain that leads down the St. Joseph Valley. This plain is entered by Pine Creek and Nottawa Creek as well as by St. Joseph River. The part traversed by Pine Creek is near the western border and is more sandy than the more central part along

Nottawa Creek. Between Pine and Nottawa creeks, in the vicinity of the hamlet of Abscota, the surface of the gravel plain is bowlder strewn for 1½ to 2 miles out from the moraine. Between Nottawa Lake and St. Joseph River, basins (one of which contains Turtle Lake, with an area of about one-half square mile) are conspicuous for 3 or 4 miles southwest from the moraine. The plain has a rapid southwestward slope, its altitude next to the moraine being about 975 feet, opposite Athens (8 or 10 miles southeast) 900 feet, and opposite Leonidas and Colon (8 miles farther) about 860 feet. Beyond the last-named place it descends perhaps 2 feet per mile down the St. Joseph Valley to the head of the Kankakee at South Bend, its altitude at that city being about 720 feet. The gravelly and cobbly part of the plain is chiefly in the rapidly sloping part above Colon, the remainder being a sand or sandy gravel.

In the St. Joseph plain are features that seem to indicate considerable filling or aggradation, and also some cutting down, for the borders of the gravel plain all the way up to the Tekonsha moraine are determined by distinct bluffs of till. The bluffs generally are only 15 to 30 feet above neighboring parts of the gravel plain after due allowance has been made for trenching of the gravel plain by modern streams. They are abrupt, as if cut down rapidly, and that, too, in a valley which from Burlington down to Colon is fully 6 miles in average width. Filling or aggradation is shown by the character of the deposits, which throughout the valley and to depths as far as the wells ordinarily penetrate (20 to 40 feet) are assorted water-laid material, strikingly different from the material of the bluffs.[1] The basins also suggest a filling of the bordering tracts, for they seem to be the result not of excavation by the glacial stream but of the melting of stagnant ice masses that persisted until the valley aggradation was completed. The most probable interpretation is that a very large valley, as broad as this gravel plain and considerably deeper than the depth of the gravel plain below the neighboring till tracts, was first excavated and afterward partly filled with the gravel and sand. It is a matter of observation that large streams like the Mississippi and Missouri rivers scour portions of their beds at flood seasons to depths approaching 100 feet, and then at ordinary river stage slowly fill the holes thus produced. The meanderings of current may in the course of time bring all parts of the valley under deep scouring action followed by partial filling, and thus give it the appearance of having once been more deeply excavated.

INTERMORAINIC GRAVEL PLAIN.

Immediately above Burlington, where St. Joseph River emerges from the Tekonsha moraine, the valley is a scant half mile in width and contrasts strikingly with the broad gravel plain 6 to 9 miles wide which the river enters immediately outside the moraine. Nevertheless, glacial drainage prevailed through this narrow part of the valley during the recession of the ice, for it served as the outlet from a gravel plain that lies within the moraine just north of Tekonsha. This latter plain covers about 12 square miles and stands a few feet lower than that outside the moraine, its altitude at Tekonsha station being 945 feet. To escape westward down the St. Joseph Valley it must have trenched the headward end of the large plain outside the moraine to a depth of 30 feet or more. This inner plain seems to have a slight slope southward from the inner part of the moraine at Nonosseppe Lake to the St. Joseph Valley at Tekonsha. Its material is a rather fine gravel, in places sandy.

GRAVEL PLAIN OF HOG CREEK.

On the outer border of the moraine immediately south of St. Joseph River a space of a mile or more carries very little outwash. Beyond this space a gravel plain extends southward past Hog Creek to the Coldwater Valley at Hodunk. It embraces what is known as Girard Prairie and covers an area of about 15 square miles. The plain has an altitude of 990 to 1,000 feet next to the moraine but slopes down to about 950 feet at the Coldwater Valley by Hodunk, a descent

[1] A boring on the Fimple farm, in sec. 20, Sherwood Township, and another on the Greenfield farm, in sec. 4, Sherwood, are each on this gravel plain and are reported to have penetrated a great depth of blue clay, presumably till, under the gravel. In the Fimple boring the gravel is 30 feet thick and the underlying blue clay was penetrated to a depth of 214 feet from surface without reaching the bottom. The Greenfield well is reported to be similar. These notes were furnished by C. E. Swain, of Sherwood, Mich.

of 50 feet in 5 or 6 miles. Bowlders are scattered over it for half a mile or more from the edge of the moraine, but are rare farther out. The material is a coarse gravel and cobble next to the moraine but becomes a finer gravel on passing out into the plain.

Basins are deep and numerous next to the moraine, one of them being occupied by a lake of perhaps 80 acres area. A mile or more from the moraine they are inconsiderable.

Numerous lines of glacial drainage in northeastern Branch County head in the moraine and lead down the Hog Creek valley across the southern edge of the gravel plain just discussed. These channels were in operation apparently until the ice border had receded into western Hillsdale County to the vicinity of Litchfield, for gravel plains west of Litchfield extend into marshy channels that lead to Hog Creek near South Butler. There appears also to have been northward drainage down Hog Creek from the vicinity of Quincy to these channels near South Butler and thence westward along the creek to the Coldwater at Hodunk. The Coldwater Valley not only served as a line of escape below Hodunk for glacial waters from the Hog Creek channels and the broad gravel plain, but also for drainage from the region now tributary to it in southeastern Branch County. One channel passes west from Quincy; another follows down the valley from a gravel plain that surrounds Coldwater Lake.

CHAPTER VIII.

MORAINES OF THE NORTHERN LIMB OF THE HURON-ERIE LOBE IN INDIANA.

By Frank Leverett.

COURSE AND DISTRIBUTION.

A broad and somewhat complex series of moraines lying along the north border of the Huron-Erie lobe in northeastern Indiana seem to be the equivalent of several moraines of the Saginaw lobe that connect with it on the north. The moraines lie entirely north of Wabash River, though for a few miles near Logansport they follow the north bluff closely.

They have their westernmost appearance on the north bluff of Wabash River a few miles above Delphi, Ind. Here they have a width of only 2 to 3 miles, but in passing northeastward across Cass County they widen to 10 miles and so continue throughout much of their course to the Indiana-Michigan line. Their width is much greater than 10 miles in the northern counties of Indiana, if the gravel plains lying between constituent ridges are included, and the combined width of the moraines proper in places exceeds 10 miles.

For a few miles west of Logansport the western or outer border of the moraines follows Crooked Creek, and the inner border lies along the Wabash bluffs, the width of the moraine here being about 3 miles. From the head of Crooked Creek the outer border leads northeastward to Warsaw, passing near the villages of Macy, Akron, and Claypool. The inner border follows up the Eel River valley to the western edge of Wabash County and then gradually bears away from the river to the north, passing about 2 miles west of Laketon, 4 miles northwest of North Manchester, 1 mile east of Sidney, and past Larwill to the head of Tippecanoe River, about 8 miles north of Columbia City. Thus far the deposits form a single massive moraine, but farther to the northeast they separate into two or more moraines, between which are gravel plains and nearly plain till tracts. From a point north of Columbia City northeastward into Michigan the inner border of the moraines is overlapped by the Mississinawa morainic system of the Huron-Erie lobe, and a little farther north it is joined on the east by the Salamonie moraine, also of the Huron-Erie lobe.

At Warsaw the outer border connects with the comparatively weak Bremen moraine of the Saginaw lobe, and between Warsaw and Claypool it connects by slight offshoots toward the northwest with the undulatory district on the inner border of the Maxinkuckee moraine. From Warsaw the outer border runs eastward past Little Eagle and the Barbee lakes to eastern Kosciusko and southwestern Noble counties where it connects with the New Paris moraine of the Saginaw lobe. (See p. 138.)

Farther east, at High Lake, about 8 miles southwest of Albion, an outer member 2 or 3 miles wide runs northward past Ligonier and Topeka to Lagrange, where it connects with the Lagrange moraine of the Saginaw lobe. The main moraine, however, continues northeastward from High Lake through the central and northeast parts of Noble and southeast part of Lagrange into Steuben County, the outer border passing near Albion, Brimfield, Rome City, and South Milford.

Between the main moraine and the outer member ridged and hummocky land is locally developed, but most of the surface is level or very gently undulating. One ridged belt runs out like a spur about 3 miles northwestward from Rome City. Other less conspicuous ridges with west-northwest east-southeast trend are found northwest of Wolcottville. An undulating

strip runs northward from Wolcottville through the eastern part of T. 36 N., R. 10 E. A poorly developed moraine on the eastern edge of a high gravel plain in northeastern Lagrange County runs northeastward from Mongo to intersect with the Sturgis moraine at Wall Lake, 2 or 3 miles west of Orland.

The outer border of the main moraine passes from Lagrange County into Steuben County on the south side of Pigeon River and crosses to the north side of the river at Flint River, 4 miles east of the county line. Thence its course is northward across the State line.

It is not easy to differentiate this main moraine from the Mississinawa morainic system which follows and laps upon its inner border. Dryer thinks that the greater part of the moraine belongs to the Mississinawa,[1] basing his opinion on its more regular surface and predominating clayey constitution; the irregular western edge he classes with the drift of the Saginaw lobe. The present writer finds evidence, however, in the distribution of outwash aprons and in the relation and connections of the several ridges of the irregular western edge that they also belong largely to the Huron-Erie lobe. (See pp. 163–164.) Dryer's line is probably not far from correct so far as it pertains to the limits of the Mississinawa system, which, from its bulk, is inferred to have overridden the earlier moraine. Possibly both have overridden a pre-Wisconsin ridge, for from studies in southeastern Michigan (see pp. 199, 261) there seems good reason to think that pre-Wisconsin drift forms a considerable part of certain massive moraines which are in line with and are apparently a continuation of this massive drift belt.

The general width of the morainic belt and of the Mississinawa morainic system, from their junction northeastward to the State line, is 10 to 15 miles, about the same as that of the moraines southwest of the junction. The combined moraines cover much of the eastern half of Noble County, about 30 square miles of the southeastern part of Lagrange County, about as much of the northwestern part of Dekalb County, and much of the western half of Steuben County. Their continuation in southeastern Michigan is considered in connection with correlative moraines of the Saginaw lobe. (See pp. 189–195.)

TOPOGRAPHY.

The moraines of the Huron-Erie lobe show a gradual and somewhat regular increase in altitude from southwest to northeast throughout their extent in northeastern Indiana. They are below 700 feet near Delphi, but reach 775 feet north of Logansport, 800 feet in northeastern Cass County, 900 feet in southeastern Fulton County, 1,000 feet in eastern Noble County, and 1,100 to 1,150 feet on the highest points in northern Steuben County.

From data furnished by deep borings it appears that the altitude of the bedrock surface does not rise toward the northeast, but is remarkably uniform at about 600 feet above sea level all along the morainic belt in northeastern Indiana. A few miles north of the State line, however, in Hillsdale County, Mich., bedrock rises very rapidly and attains an altitude of over 1,100 feet. The great drift accumulations in northeast Indiana are laid down, as it were, in the lee of the prominent table-land of sandstone of the Marshall formation that has its southern terminus in Hillsdale County, Mich.

In Whitley, Kosciusko, Fulton, Wabash, Miami, and Cass counties the moraines form the divide between Tippecanoe and Eel rivers, both of which are tributary to the Wabash. North of the head of the Tippecanoe the several headwaters of Elkhart River find their source in these moraines and lead northwestward to St. Joseph River and thence to Lake Michigan. The opposite or southeastern slope of the moraines is drained by tributaries of the St. Joseph (of the Maumee), which belongs to the Lake Erie drainage. In Steuben County these moraines are traversed from east to west by three small streams, Turkey Creek, Pigeon River, and Crooked Creek, which have their sources near its eastern border on much lower land than the main crest of the moraine. Their discharge is into St. Joseph River and thence to Lake Michigan.

In most places the drainage divide is at the crest of the main moraine, most of which is higher than the general level of the western edge, though some prominent points along the western edge are as high as the main crest. The relief of the main crest above the outer

[1] Dryer, C. R., Eighteenth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1894, pp. 83–90.

border district is generally between 50 and 75 feet and above the plain on the inner or eastern border 100 to 150 feet, the country to the southeast being lower than that to the northwest.

The topography of the southwestern portion of this series of moraines in Cass County and northern Miami County, Ind., is of a swell and sag type in which there are few basins. The swells are 10 to 40 feet in height and are closely aggregated, giving the moraines a strong expression compared with the nearly plane district to the northwest. Lake basins become conspicuous in southeastern Fulton and northwestern Wabash counties and continue numerous all along the morainal belt to the northeast. They are much more prominent on the northwestern or outer slope than on the southeastern or inner slope and are especially numerous where moraines of the Saginaw lobe connect with these moraines. The largest lakes exceed a square mile in area, and one, James Lake, has an area of 2.6 square miles; the majority, however, cover but a small fraction of a square mile and some occupy but a few acres. Many of them have depths 50 to 75 feet or more below the level of the outlets and more than 100 feet below the surrounding parts of the moraine. James Lake, with a reported depth of 87 feet, has on its eastern border hills that rise more than 100 feet above the water surface, thus giving the basin a depth of about 200 feet below the neighboring hills. The highest knolls along the moraine are probably those in northern Steuben County, which rise more than 100 feet above bordering sags. Knolls 50 to 60 feet in height are found at short intervals as far southwest as northern Wabash County, but most knolls are only 20 to 40 feet high and many of them rise less than 20 feet above the bordering sags. On the inner slope of the moraines few knolls exceed 40 feet in height and the general expression is much less varied than on the outer slopes. Marshes and nearly plain tracts are also much less common on the inner slope than on the outer. In places on the outer slope sharp ridges known as "hogbacks," some of which perhaps are to be classed as eskers, are not uncommon; they are, however, very short, none exceeding a mile in length having been observed. They commonly form the borders of lake basins; one lake in Steuben County has received the name "Hogback Lake" because of its close association with one of these ridges.

On the outer slope of the moraine deep indentations show where lines of glacial drainage lead away from the moraine. In Steuben County these glacial channels have their heads on the inner border of the moraine and thus completely traverse the moraine. One of them is occupied by Turkey Creek, another by Pigeon River, and a third by Concord Creek and a string of lakes tributary to Crooked Creek.

STRUCTURE OF THE DRIFT.

COMPOSITION.

It is somewhat difficult to set forth clearly the structure of this massive morainic belt because of the great differences it displays both horizontally and vertically. Extensive areas in the southwestern part and along the inner or southeastern slope of the belt are covered with clayey till, but many of them are underlain by thick deposits of sand and gravel. The clayey till is apparently thickest in the low-lying southwestern part of the belt in Cass and Carroll counties.

The outer slope of the belt of moraines shows extreme variability in surface structure, the deposits ranging from stiff clayey till to coarse cobble and gravel. There are no extensive areas of any one kind of deposit. However, gravelly and sandy drift seems to increase and clayey drift to decrease from the main crest of the belt toward the outer border. The gravelly and cobbly knolls and ridges are more or less definitely related to and grouped around the heads of the gravel plains that lead away from the moraines and that were formed by the waters discharged from the ice. Much of the drift on the outer slope is a loamy sand, not definitely assorted, but looser textured than the till of the main crest and the southeastern slope. Local occurrences of very stiff clay, however, were noted.

In northeastern Lagrange and northwestern Steuben counties a very sandy tract with uneven surface, containing both basins and knolls, rises abruptly at its western edge into an elevated gravel plain. This sandy tract was probably covered by the Huron-Erie ice at the time

the higher gravel plain was building, or was perhaps occupied temporarily by a lake which was drained later by the cutting down of its outlet across the gravel plain. The sand might thus be an outwash from the ice, which settled in the bed of the lake. The district is sparsely settled and has only a few shallow wells, so the character of the material below the surface sand is not known.

South of Pigeon River considerable clayey till occurs between the Lagrange moraine and the more bulky moraine to the east in south Lagrange County, but its continuation into Noble County is loose textured.

BOWLDERS.

Bowlders are more plentiful and at the same time less regularly distributed on the outer than on the inner part of the morainic belt, but are not rare in either situation. The number on the outer part compares favorably with the number found in the several moraines of the Saginaw lobe (Maxinkuckee, New Paris, Middlebury, Lagrange, and Sturgis), which connect with this morainic belt. One of the most striking accumulations in the region is found, however, not on the morainic belt but in the Wabash Valley near Logansport, in whose outskirts there are hundreds if not thousands of bowlders to the acre. As the Wabash is a comparatively weak eroding agent these bowlders must have been concentrated by the erosion of the moraine and the removal of its finer parts by the outlet of Lake Maumee. Some bowlders are scattered over the gravel plain on the outer edge of the morainic belt, good illustrations being found in eastern Lagrange County both north and south of the Pigeon River valley.

THICKNESS OF THE DRIFT.

Well data.—The search for natural gas about 1886 led to the making of several deep borings in the region traversed by this morainic belt. Though not successful in finding gas these borings throw some light on the structure of the drift in places where it is especially thick.

In the northern part of the district, in Steuben, Dekalb, Whitley, and northern Allen counties, the thickness of the drift is very great, but farther south it is relatively thin. Ordinary wells for farm and domestic use reach rock in southern Allen, much of Huntington, southern Wabash, and all of Wells and Adams counties, except when in the line of deep preglacial valleys.

Steuben County.—Records of farm wells in eastern Steuben County show nearly continuous till to 100 feet and even to 150 feet. In places, however, as in the vicinity of Fish Lake in the southeastern part of the county, the drift is gravelly and wells are obtained at depths of 25 feet or less.

A well at the Tri-State Normal College in Angola, 104 feet in depth, may have been largely in pre-Wisconsin drift, for after penetrating 23 feet of yellow and blue till of the Wisconsin drift it entered a reddish stony till with sandy pockets too small to yield much water. This clay continues 75 feet to a water-bearing gravel at bottom. The ground here is about 35 feet lower than on neighboring knolls and ridges in the southern part of the village.

Many wells on the high part of the moraine from Angola southwestward are 80 to 100 feet and some of them are 160 feet in depth. They ordinarily penetrate loose-textured drift with a water table 75 feet or more below the surface. Some of them, however, are reported to have penetrated much blue till. Exposures along roadsides and in ravines show stony till of very loose texture.

Lagrange and Noble counties.—Numerous shallow flowing wells exist in southern Lagrange and northern Noble counties in a plain between the Lagrange moraine and the main moraine to the east. Most of them are on low tracts a few feet below the level of the bordering plain near Elkhart River and some of its tributaries, the head apparently being insufficient to give flows on the plain. Many are only 10 to 20 feet deep and the occurrence of flows from such slight depth seems all the more remarkable from the fact that there are no tracts markedly higher in the immediate vicinity to serve as or suggest the source of the artesian head. The elevation above sea level to which the water rises decreases 60 feet from northeast to southwest

in the 8 miles from Wolcottville to Wawaka, being about 955 feet at Wolcottville, 930 feet at Rome City and in wells in secs. 3 and 10, T. 35 N., R. 9 E., and about 895 feet around Wawaka.

The underground relations are so little understood that it can not be stated that the wells are all in a single pool. A single well or a small group of wells may be controlled by local conditions in its catchment area and underground flow and be independent of the remainder of the wells. Possibly the catchment area or areas will prove not to be in the immediate vicinity but in a more or less remote district of higher altitude. In that case the shallow wells may strike water that rises through fissures in the till from considerable depth. Numerous springs along the shallow valleys in the plain around Wawaka may also prove to rise from considerable depth.

The deepest flowing well reported is 1½ miles west of Wawaka on the farm of John Pasch. The following record was obtained by Dryer:

Record of Pasch flowing well near Wawaka, Ind.

	Feet.
Gravel	6
Quicksand	40
Clay, blue	34
Gravel	2
Clay, blue	77
Gravel, cemented	7
	166

The shallow wells east and south of Wawaka, with depths of 10 to 20 feet, are driven through a few feet of clay and are apparently in sand or fine gravel at the bottom. One of the strongest, that of Abram Frank, a mile east of Wawaka in the east part of sec. 27, is only 10 feet deep and flows 2 or 3 barrels a minute. It fills a pond used for fish culture and then runs to waste in a stream that compares favorably in size with the neighboring brook into which it discharges.

At the Rome City sanitarium the wells range in depth from 16 to 40 feet and obtain their supply from gravel below blue clay. The head is 4½ feet above the level of the large reservoir at this village, or about 931 feet above sea level. The flowing wells at Wolcottville are 53 to 65 feet deep and penetrate 20 feet of surface gravel overlying blue till to the water bed. They are on low ground along Elkhart River and have a head only 5 feet above the surface.

Several wells on the west side of Elkhart River south of Eddy in secs. 3 and 10, T. 35 N., R. 9 E., range in depth from 60 to 88 feet. One at a schoolhouse in sec. 10 flowed when first made, but in 1902 the water lacked 2 or 3 feet of reaching the surface. The deepest well (88 feet) on the Conrad estate in sec. 3 flowed 5½ gallons per minute at 3 feet above the surface in 1902. These wells have about the same altitude as those in Rome City, 930 feet above sea level.

A so-called "blowing well" was noted at a farmhouse a mile south of Albion. The well is 68 feet deep and was largely through dry gravel and cobble. The blowing or whistling occurs when barometric conditions cause the air in the gravel to be expelled.

In northeastern Noble County at Kendallville a deep gas-well boring shows the drift to be 485 feet deep. Specimens of the drillings, preserved in a glass tube, show that the material is nearly all sand and fine gravel below 20 feet of yellow till. A record of a water well at Dr. Mayer's residence in Kendallville, furnished by the driller, is as follows:

Record of Mayer well, Kendallville, Ind.

	Feet.
Clay, surface	5
Gravel, dry	20
Gravel, water bearing	10
Clay, soft, blue	25
Gravel, water bearing	20
Till, hard, bluish (pre-Wisconsin?)	70
Till, soft, blue	25
Gravel, water bearing	10
	185

Another well in Kendallville 108 feet deep did not strike the hard till.

A well 3 miles east of Kendallville, in sec. 1, T. 34 N., R. 11 E., penetrated yellow till to about 14 feet and then blue till with thin beds of sand or gravel to 206 feet. A well 4 miles northeast of Kendallville is reported to have penetrated nothing but till to 120 feet, but neighboring wells strike water-bearing gravel or sand at moderate depths.

A gas-well boring at Albion was observed during drilling by Prof. W. B. Van Gorder, who furnished the following record:

Record of drift beds at Albion, Ind.

	Feet.
Clay, yellow	10
Clay, blue	10
Sand and gravel	115
Clay, blue	20
Sand and gravel, with streaks of blue clay	52
Sand and gravel	81
Clay, blue, with thin beds of sand	52
Gravel	5
Bowlder clay, red	15
Sand	5
Slate (?)	1
Sand	9
Total (assorted material 267, clay 107, slate 1)	375

The boring penetrated till and assorted material in alternating beds, of which the till comprises only 30 per cent and the assorted material 70 per cent. If the several drift sheets were widespread it might be concluded that there were stages of melting and outwash followed by readvance of the ice and deposition of till. But numerous natural exposures and well records show that the till grades horizontally into gravel or sand and back again to till within short distances. Local conditions within and beneath the ice instead of great oscillations of the ice border seem to have determined the character of the beds.

At Ligonier, in northwestern Noble County, the drift is known to be only 169 feet. No further data were obtained.

Kosciusko County.—Two gas-well borings at Warsaw penetrated 247 and 255 feet of drift. A boring 3 miles west of Warsaw penetrated 243 feet of drift. In all three borings sand and gravel greatly predominate over the till. In one well water was flowing strongly from the top of the 7-inch pipe 2 feet above the surface at the time of the writer's visit. As the water contains much sulphureted hydrogen, a portion of it at least is from the rock. It is thought, however, that much of it is from the drift.

Whitley County.—At Larwill, on an elevated part of the moraine 103 feet higher than Warsaw, there is 365 feet of drift. The upper 100 feet is chiefly rather clayey till, overlying mainly sand and gravel. Records of two other deep wells east of this moraine belt are presented on page 171.

OUTWASH.

OUTWASH IN INDIANA.

DISTRIBUTION AND CHARACTER.

Swampy and somewhat sandy tracts that set in on the outer or northwest border of this morainic belt near Lake Cicott and continue 7 or 8 miles eastward to the head of Crooked Creek north of Logansport seem to be outwash from it. Sand appears also in a ridge several miles in length that borders and to some extent rides upon the outer slope of the moraine; but this was probably drifted up by the wind. Northeastward from the head of Crooked Creek, across northern Cass, southeastern Fulton, and southwestern Kosciusko counties little outwash is found until the Tippecanoe Valley is reached near Warsaw, the moraine in this interval of about 30 miles fronting on a plain of clayey till. From the Marshall-Kosciusko county line eastward along the Tippecanoe Valley to Warsaw a sandy and gravelly plain lies mainly south of the

stream and apparently rises toward the moraine whose edge is 1 to 3 miles south. The material in this plain is fine, indicating rather weak discharge, and its extent is small, for it becomes inconspicuous in western Kosciusko County.

Farther up the Tippecanoe across Bone Prairie and Turkey Prairie eastward to Tippecanoe Lake a sheet of gravel of medium coarseness, spread over about 50 square miles, may have been in part outwash from the Saginaw lobe. Farther east in the vicinity of the Barbee Lakes and Tippecanoe Lake the outwash is sandy.

A conspicuous gravel plain south of Elkhart River in western Noble County abuts at the east against sharp morainic ridges of the Lagrange moraine and at the north fronts on a bowlder-strewn plain along Elkhart River. Its position indicates derivation from the Saginaw as well as from the Huron-Erie lobe, and this interpretation is sustained by the character of the material and the slope of the plain. The material is a coarse gravel and cobble on the north and east and becomes a fine gravel toward the southwest, and the plain slopes southwestward. That the Huron-Erie lobe probably persisted longer than the Saginaw has already been indicated, and is apparently supported by certain features of this gravel plain, on whose southern edge a shallow but broad valley heading in the Huron-Erie correlative of the Lagrange moraine east of Cromwell seems to have been produced by drainage from the Huron-Erie lobe after the cessation of the outwash from the Saginaw lobe.

A plain lying along the outer border of the Lagrange moraine between the Elkhart Valley at Ligonier and the intersection of the Huron-Erie with the Lagrange moraine near Lagrange is covered in part by a thin deposit of clay or clayey till but generally has gravel and sand at the surface. In the clayey portion the sand and gravel are sufficiently near the surface to give underground drainage. The clay is present from near Ligonier northward past Topeka and extends 2 or 3 miles out from the moraine, terminating in a feather edge. It carries a few surface bowlders and is probably to be regarded as a till sheet, though in places nearly free from pebbles. The gently undulating western slope of the moraine near Topeka also has a clayey till of considerable depth. The conditions here are the reverse of those common in outwash aprons, in most of which sand and gravel extends up to the moraine as a continuous surface sheet and even laps upon the edge of the moraine as a coating to the knolls and as a filling in sags. Here, however, the outer slope of the moraine is nearly free from surface gravel and the till extends out into the gravel plain. West and southwest of Topeka wells with depths of 50 to 75 feet are entirely through gravel and sand after passing through the thin surface capping of till. This district is known as the "Haw patch" and is one of the most productive farming areas in Indiana.

Within 2 or 3 miles northeast from Topeka sandy deposits set in on the outer edge of the moraine, but soon give place to gravel and cobble which extends to the head of the reentrant between the Lagrange moraine and its equivalent in the Huron-Erie lobe. It is naturally to be expected that drainage here would have been exceptionally vigorous. The strongest outflow (see p. 145) appears to have been from the Huron-Erie side of the reentrant.

East of the Lagrange moraine in northern Noble County gravelly plains of limited extent appear at two places, but in general no conspicuous outwash lies along this part of the moraine. One gravelly plain with an area of 3 or 4 square miles lies along the east side of the south fork of Elkhart River in the north part of T. 34 N., R. 9 E. Its surface is not so level as that of the typical outwash apron, but shows gentle swells 5 to 10 feet high and marshy basins, some of which are occupied by lakes. Within a mile southeast of the edge of this gravelly district a very stiff clayey till sets in and extends southeastward beyond Albion. North and northeast of the gravelly district a very loose textured till extends to the north fork of Elkhart River and Waldron Lake.

The second gravelly district extends westward from Rome City into the bend of Elkhart River. It is a pitted plain near its eastern end and has sags and poorly drained depressions interspersed with dry strips of gravel. North of this gravel plain a sharply rigid strip of rather loose textured drift trends east-southeast and west-northwest. Possibly the gravel plain was formed as an outwash during the development of this ridged belt, for the latter has a more

strongly morainic aspect than the drift on the immediate southeastern and southern borders of the gravel plain. The record of a deep well on the Rhinehart farm, 2 miles west of Rome City, shows sandy gravel, with water in its lower half, extending to 52 feet, 40 feet of blue till, and 24 feet of water-bearing sandy gravel, giving a total depth of 117 feet.

GLACIAL DRAINAGE.

In eastern Lagrange and northwestern Steuben counties conspicuous gravel plains lie along the northwestern border of the main moraine each side of Pigeon River. The portion south of the river in eastern Lagrange County contains coarse gravel and cobble and is coated to a considerable extent by a thin deposit of earthy material in which large bowlders are embedded. It stands 30 to 40 feet above a sandy tract along the river. In respect to bowlder capping, as well as in altitude, it is similar to the high plain north of Mongo, discussed in connection with the Sturgis moraine (p. 150). The ice sheet apparently occupied this gravel plain and that north of Mongo while depositing the surface capping of bowldery material. Its recession from this plain seems to have been somewhat irregular. The lower district along Pigeon River, it is thought, held a mass of ice in the district east from Mongo for some time after the ice had withdrawn from the higher districts south of it. Otherwise it should have been built up to a level corresponding to that of the higher plain. In northwestern Steuben County the high plain is more sandy than in eastern Lagrange County, and in places it carries low dunes. It extends back into recesses in the moraine at the Pigeon Valley and farther north at Gage Lake. In these recesses, as well as along Turkey Creek in eastern Lagrange County, it is moderately trenched by lines of glacial drainage that lead through the main moraine from a lesser moraine on its inner border.

The line of glacial drainage in the Turkey Creek valley heads at Little Turkey Lake on the southern edge of Steuben County, about a mile west of Hudson-Ashley. In its course through the large moraine it occupies a valley whose general width is nearly a mile, though somewhat narrower near the outer border of the moraine near Springfield (or Brushy Prairie). A chain of lakes is found along its course, one of which, Turkey Lake, is 75 feet in depth. It is probable that stagnant ice masses persisted at the site of these lakes during the deposition of the sandy gravel in this line of glacial drainage.

Pigeon River was utilized as a line of glacial drainage until the ice had withdrawn to the Wabash moraine, which lies east of and is distinct from the moraines under discussion. The present stream follows the outer border of the Wabash moraine southward for about 12 miles, and then turns westward to enter the main moraine of the belt under discussion about 3 miles below the village of Pleasant Lake. It emerges from this moraine 6 miles farther down, at Flint, and traverses a gravel plain for the remainder of its course, except at Mongo, where it passes the weak outlying moraine of the belt. It has in its passage through the main moraine a valley about one-half mile in width, with bluffs 30 to 50 feet high from which there is a rise into the moraine. Along its course through the main moraine it flows through a chain of lakes, of which Long, Golden, and Hogback lakes are the largest. Hogback Lake has its longest diameter athwart the course of the channel and extends back into the moraine at either end, but Long and Golden lakes have their longer axes in harmony with the axis of the channel. The gravel and sand of the glacial drainage line form a low terrace along the stream and around the borders of the last-named lakes, but are completely interrupted at Hogback Lake. The lakes are about 40 feet in their deepest parts and in all probability occupy basins in which stagnant masses of ice persisted during the use of the channel as a line of glacial drainage.

A third line of glacial drainage that traverses the main moraine is found in a plain that sets in about 3 miles north of Angola and leads westward. This plain is bordered on the east and south by a gently undulating till tract and on the north by a very prominent morainic accumulation carrying points that rise 100 feet above the plain and nearly 1,150 feet above sea level. The plain is about a mile wide and extends westward from secs. 11 and 14, T. 37 N., R. 13 E., to Crooked Lake in secs. 9 and 16 of the same township. It also touches on the north the south-

ern end of James Lake. The main line of discharge for glacial waters appears to have been over the basin occupied by Crooked Lake, for the gravelly plain is continued at the western end of the latter. It passes across the basin of Gage Lake, where it emerges from the main moraine. Gage Lake is bordered on the northeast by another gravel plain, whose surface is 45 feet, by hand level, above the water, and is 25 feet above the surface of the plain along the Crooked Lake outlet. As the depth of water reaches 70 feet the bottom of the basin is 115 feet below the higher gravel plain and 90 feet below the lower plain. Crooked Lake is in a shallower basin, its bed being scarcely 50 feet below the bordering gravel plain at its eastern end. The plain that heads east of Crooked Lake has a sandy gravel and seems not to have been formed by very vigorous drainage. The higher plain that sets in at the east end of Gage Lake carries much cobble and coarse gravel and seems to have been at the head of a vigorous point of discharge.

OUTWASH IN MICHIGAN.

A gravel plain having an altitude of about 975 feet at the Michigan State line descends northward to about 920 feet at Prairie River, 2 miles south of Bronson. North from Prairie River the plain is shown by the drainage and by barometric determinations made by W. F. Cooper to be a little higher on its eastern than on its western border, being about 940 feet on the east and 920 to 930 feet on the west. The slopes, therefore, seem to support the view that the plain was built up in large part at least by outwash from the Huron-Erie lobe on its eastern side rather than by outwash from the Saginaw lobe, as it receded lengthwise of the plain. The character of material is in harmony with this interpretation, cobble and coarse gravel being more conspicuous on the southeastern edge of the plain than elsewhere. Prairie River finds its source in a large marshy plain that extends up into the moraine about to the State line, and that seems to have been a place of discharge from the ice after the latter had receded a few miles from the position it held while the large gravel plain was forming.

Another extensive gravel plain heads in the midst of the main moraine of this belt just north of the State line in the southeastern township of Branch County, Mich., and extends northwestward to join the one just described near Coldwater. For 10 miles from its head its average breadth is about 4 miles and its maximum nearly 6 miles. Farther north it is reduced to a width of about a mile and is bordered by distinct bluffs, as if trenched by a stream. The broad gravel plain is not bordered by definite bluffs. The plain has numerous dry basins near its head and farther down it contains several lakes, the largest of which, Coldwater Lake, has an area of about 2 square miles. Considerable cobble and coarse gravel occupies the head of this plain in the vicinity of the hamlet of California, becoming finer northwestward or down the slope of the plain. The altitude at the head of the plain is 1,020 to 1,030 feet, as determined barometrically by W. F. Cooper, but it drops to about 975 feet at the south end of Coldwater Lake, or about 50 feet in 5 or 6 miles. Farther north the descent is more gradual, being only 70 feet from Coldwater Lake along the Coldwater Valley to the St. Joseph Valley at Union City, a distance of fully 20 miles.

From Coldwater Lake a sandy strip 1 to 2 miles wide runs northeastward to Quincy. In it there is a chain of lakes, of which Marble Lake near Quincy is the largest, its area being little less than that of Coldwater Lake. This sandy strip is probably a line of glacial drainage, though at present the water divides about midway of its course, and the altitude seems to be slightly higher toward the northeast than toward Coldwater Lake. From Marble Lake there may have been glacial drainage southwestward through this sandy depression to Coldwater River at Coldwater Lake, and also westward to the same stream near the city of Coldwater. The outwash from Quincy northwestward along the border of the Tekonsha moraine is discussed in connection with that moraine (p. 152).

INNER BORDER.

DISTRIBUTION OF THE MORAINES.

The district east of this morainic belt in northeastern Indiana was discussed in some detail in Monograph XLI, and only a few general observations seem necessary here. The Mississinawa morainic system and the Salamonie, Wabash, and Fort Wayne moraines come into Indiana from northwestern Ohio separated by intervals of 10 to 15 miles and follow nearly parallel northwestward courses to the main axis of the Maumee-Wabash basin. Beyond this axis they turn northeastward and their parallelism is less marked. The outer two moraines are somewhat distinct from each other and from the great morainic system outside as far north as Columbia City, beyond which they coalesce and bank up against the inner face or slope of the great morainic system. The inner two lie closer together in this northern district than in the district south of the axis but remain distinct from each other and from the moraine outside throughout their course in northeastern Indiana. St. Joseph River (of the Maumee) flows between them. In southeastern Michigan all these moraines merge with the great interlobate belt that follows the "thumb" of Michigan and separates the Huron-Erie from the Saginaw lobe.

MISSISSINAWA MORAINIC SYSTEM.

The Mississinawa morainic system has a general width of 5 or 6 miles and is in places separable into two or more moraines, between which are narrow stretches of till plain. It has a swell and sag topography with few sharp knolls and few basins where not combined with the greater morainic system. Its relief above the outer border plain ranges from 20 to 75 feet and its front is rather steep. Its drift is largely a clayey till and carries much fewer bowlders than does the large morainic system with which it becomes blended at the north. This morainic system correlates somewhat closely with the Kalamazoo morainic system of the Saginaw and Lake Michigan lobes. Its outer border is followed by Mississinawa River, from the Ohio-Indiana State line northwestward nearly to the Wabash, and it is because of its close association with this stream that it has received the name Mississinawa. The bordering plains on either side of the system are of stiff clayey till and their surface is nearly free from knolls or noteworthy features.

SALAMONIE MORAINE.

The Salamonie moraine has scarcely half the average breadth of the Mississinawa system and in its northern part is in places only 1 or 2 miles broad. At several places along its course it bears groups of conspicuous gravelly knolls, some of which are 60 to 80 feet high. Its greater part, however, presents a subdued swell and sag topography, the swells being only 15 to 20 feet above the sags. North of Wabash River, in southern Whitley County, it is reduced to a low, rather smooth ridge differing but little in topography from the border plain but having a larger number of surface bowlders. The moraine is followed on its outer border throughout much of its course from the Ohio line to Wabash River by Salamonie River, from which it takes its name. There is no continuous gravel plain along the border of the moraine, but the amount of gravel and sand is greater than it is along the Mississinawa system.

WABASH MORAINE.

The Wabash moraine is similar to the Mississinawa system in topography and governs the course of Wabash River from near the Ohio line northwestward to where the river turns westward down the axis of the Maumee-Wabash basin. Its breadth is but 2 to 4 miles. It has an abrupt outer-border relief of 20 to 50 feet along much of its course from the State line to the axis of the basin, but from the axis northward its relief is less conspicuous and seldom exceeds 20 feet. This moraine not only controls part of the course of the Wabash, as indicated above, but in its northern extension partly controls Aboit River, Cedar Creek, and Pigeon River. Each stream in turn follows it for some distance; Pigeon River turns westward to pass through the great morainic system; Cedar Creek turns eastward through the Wabash

moraine to enter the St. Joseph (of the Maumee), and Aboit River passes directly down the axis of the basin along the old outlet of the glacial lake Maumee to Wabash River. Very little sandy or gravelly outwash is seen on the outer border of the Wabash moraine, the streams having their courses through till plains. Some sand and gravel occurs along the Pigeon. A gravel plain on the outer border of this moraine a few miles north of Fort Wayne at the head of Eel River seems to be an outwash from it. The drainage for glacial waters from the southwest-flowing part of Cedar Creek may have been across this gravel plain to Eel River. It is probable also that the Wabash afforded a line of escape for the glacial waters in the vicinity of the axis of the basin.

FORT WAYNE MORAINE.

The Fort Wayne moraine follows the north side of the St. Marys River valley from the Ohio line northwestward to Fort Wayne, and the east side of the valley of the St. Joseph (of the Maumee) from Fort Wayne northeastward into northwestern Ohio. It has a general width of 3 or 4 miles and presents a gently undulating surface with less strength of expression than any of the other outlying moraines of this series. Its main crest is 50 to 75 feet above the beds of the streams that follow the outer border. The streams are in shallow trenches usually 20 to 30 feet deep and the moraine has a relief of 30 to 50 feet above the bluff or plain bordering the valley. The outer slope is a mile or more across, being scarcely as steep as in the moraines outside. The drift in this moraine is largely a clayey till and carries but few bowlders on its surface. The moraine may have had some outwash into the St. Joseph Valley, along which there is a strip of gravelly land; but wells show that the gravel extends to great depth and that it appears to pass under the till of the moraine. Probably only the surface portion, including perhaps that standing above the level of the present stream, is to be correlated with the Fort Wayne moraine. These gravel deposits extend beyond the mouth of St. Joseph River into the bend of St. Marys River in the west part of Fort Wayne. There is no evidence of vigorous outwash into the St. Marys Valley above Fort Wayne.

AREA EAST OF THE FORT WAYNE MORAINE.

By Frank B. Taylor.

The area east of the Fort Wayne moraine is described by Mr. Leverett in an earlier report,[1] but the completion by the United States Geological Survey of topographic maps covering the district between Findlay and Delphos, Ohio, made a reexamination very desirable. The area is one in which the beaches of Lake Maumee approach the front of the Defiance moraine near Findlay and appear to afford excellent opportunity for the study of the deforming effect of ice attraction on contiguous lake waters. (See pp. 342–346.) The writer spent a short time studying this and related areas in 1908 and 1909.

Although the recent detailed studies in this area are very incomplete and fragmentary, the results are important for several reasons. Hitherto the interval between the Fort Wayne and Defiance moraines has been represented as devoid of terminal moraines. This stretch of 45 miles is unusually wide for an intermorainic space and has been something of a puzzle to glacial geologists for many years. The studies recently made seem to show that this interval is in fact occupied by several faint terminal moraines, most of which, so far as known, are crowded into the western part of the area and seem to be closely related to the Fort Wayne moraine as previously mapped.

At least two faint moraines pass through that area between the Fort Wayne and Defiance moraines. They run in courses nearly parallel with the main or frontal crest of the Fort Wayne moraine in the vicinity of Lima, Ohio, and appear to be related to it. One of them passes west from Mount Cory to Bluffton, where it turns southwestward and passes a mile or so south of Cairo and Elida; this may be called the Bluffton moraine. Another fainter ridge runs west from Rawson and curves to the southwest roughly parallel with the Bluffton moraine

[1] Leverett, Frank, Glacial formations and drainage features of the Erie and Ohio basins: Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 566–581.

and 2 or 3 miles north of it; this may be called the Rawson moraine. The Bluffton moraine is so clearly developed as a distinct individual that it seemed worth while to look for others and if possible to work out their relations to the Fort Wayne moraine and to Lake Maumee. It was not possible to do this in detail, but the general relations were made out.

It was thought at first that the passage of one of these moraines beneath the level of Lake Maumee might account for certain peculiarities of the Maumee beach, especially for its northward bulge between Delphos and Van Wert and perhaps for other similar features between Van Wert, Ohio, and New Haven, Ind.

The investigation was not carried far enough to test this matter fully. It was found that the northward bulge of the beach east of Van Wert is in all probability due to a moraine passing lakeward, but this moraine was not identified with either the Bluffton or the Rawson moraines, but appears to be inside of both of them and of later date. The area west and northwest of Lima was not examined in enough detail to make sure of the identity of the Bluffton and Rawson moraines west of Ottawa River. But west of the meridian of Delphos more moraines of the same character and having the same relations to the Fort Wayne moraine were found and followed into Indiana. Besides the faint moraine which causes the bulge of the shore east of Van Wert, there is another which passes northwest from Conway, Ohio, and affects the shore slightly; it is probably continuous with a faint ridge 1½ miles south of Van Wert.

At Landeck, 3 miles southwest of Delphos, there is a ridge which becomes distinct a mile or so northwest of Venedocia and runs thence unbroken to or beyond Monroeville, Ind. Through much of this distance, especially toward the northwest and in Indiana, this ridge is distinctly double and throughout nearly the whole distance it is sharply defined by a well-developed channel of ice-border drainage along its front. The flat floor of this drainage line is well developed at the south edge of Venedocia and is easily followed for 2 miles westward to Little Auglaize River. Long Prairie ditch, which comes in from the west at this point, follows the bed of this glacial stream in a reverse direction. The channel itself continues west, passing a mile north of Ohio City and past Glenmoore, receiving headward tributaries of Town Creek between these two towns. North of Glenmoore the moraine turns northwestward, but the drainage channel continues westward to Wren and thence southwest through the front ridge of the Fort Wayne moraine to St. Marys River. From Glenmoore northwest to Middlebury and perhaps to Wolfcale the ground in front of the moraine is a flat floor without any evidence of border drainage, but near Wolfcale a smaller border drainage channel begins and is particularly well defined from Wolfcale to Monroeville between the two parallel ridges of the moraine.

Eastward from Venedocia the moraine is somewhat fainter to Auglaize River, 1 mile northeast of Southworth. The drainage channel also becomes fainter in the same interval and was not clearly made out at Southworth, but it may be there, nevertheless, for the tract between Southworth and Cairo has not been examined. This ridge between Venedocia and Monroeville appears to lie inside of and hence is probably later than the Bluffton moraine, but may be the westward continuation of the Rawson.

In Ohio, west of Auglaize River through southern Van Wert County, the minor drainage strongly suggests another moraine and line of ice-border drainage between the one just described and the main ridge of the Fort Wayne moraine, which runs close along the north side of St. Marys River; and the same suggestive arrangement of drainage continues in Indiana to the Maumee River. Indeed, the minor drainage southwest and west of Monroeville indicates two and probably three ridges between the Monroeville ridge and the front or main ridge which passes just west of Hoagland, Ind.

In the eastern part of Allen County, Ind., another moraine, well defined for its type, runs southeastward from Gar Creek, passes just south of Dawkins, and, after crossing the State line into Ohio, passes southeastward between Magill and Batson. This moraine lies 5 miles northeast of the ridge at Monroeville and is very different from it in character. It is water-laid and finds physical expression only as a very low, smooth swell or ridge in the flat plain of the old lake floor. It is, however, very persistent and characteristic in its relation to the valley slope. It has a definite trend in a broad graceful curve and controls the minor drainage The

observations thus indicate that there are at least six or seven weak ridges inside of the main front ridge of the Fort Wayne moraine.

The investigation on the north side of the Maumee Valley was less complete than that on the south side, but two and possibly three such ridges were found and two others seem to be indicated by the drainage lines. One moraine in particular is clearly developed just west of Bryan above the upper Maumee beach and was easily traced northeast to a point east of Alvordton and southwest to a point beyond Farmers Center. Throughout the whole distance this moraine is bordered along its front by a sharply cut drainage channel one-eighth to one-fourth mile wide, and it crosses divides between streams without interruption. The investigation was not carried far enough, however, to make sure of its identity southwest from Farmers Center. Faint morainic fragments between Fanster, Ind., and Link, Ohio, on the north side of Maumee River appear to be a northeastward extension of the moraine southeast of Gar Creek and possibly connect with the moraine west of Bryan; but this correlation is not yet established.

The country slope from the main ridge of the Fort Wayne moraine is shorter and therefore steeper on the north side of Maumee River than it is on the south side. From this fact it would be expected that any weak moraines on the north side would be more closely set together and perhaps less readily distinguished as individuals. So far as made out the series on the north side seems to correspond in a general way to that on the south side, indicating a symmetrical disposition of the ridges; but actual identification was not made.

Minor drainage concentrates along a line running north from Sherwood and turning gradually eastward past Ney and Glenburg. This line was found on examination to be characterized by scattered low knolls and scattered bowlders protruding from a plain composed largely of lake clay without bowlders. This apparently marks the course of another moraine distinctly inside the Gar Creek ridge. It is not improbable that still another, perhaps largely concealed under lake clay, runs south between Powell Creek and Auglaize River. If there is a moraine between these streams it probably passes near Arthur and Continental, crossing the Blanchard River near Leon and curving gradually eastward north of Kalida and Pandora. The drainage strongly suggests a faint drift ridge in this position, but it has not yet been fully traced in the field. The moraine west of Bryan is perhaps to be correlated with the "Middle moraine," or outer Defiance ridge, which Mr. Leverett[1] found between the Fort Wayne moraine and the inner Defiance ridge in the Ann Arbor area.

Although incomplete, this investigation shows that the Fort Wayne moraine like the Port Huron morainic system is composite and is made up by the merging together of a number of ridges into a single broad belt. The Defiance moraine in Ohio has not been studied from this point of view, but its breadth and strength strongly suggest composite form also, and it is known to be double in part of the Ann Arbor quadrangle. The Defiance, however, is so extensively water-laid that its constituent ridges may not be distinguishable, unless in such forms as the faint bowldery belts which Sherzer has found in Monroe and Wayne counties, Mich.

WELL DATA.

By Frank Leverett.

Dekalb County.—Over the greater part of Dekalb County a sheet of till extends to an average depth of about 50 feet. Below the till the drift appears to be largely sand and gravel. The gas-well boring at Butler, in the northeast part of the county, is reported by Dryer to have penetrated the following beds. The compact clay near the bottom of the drift and the overlying red quicksand are probably pre-Wisconsin. It seems not unlikely that much of the great body of gravel and coarse sand is also pre-Wisconsin.

[1] Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1908. See also revised edition of 1915 and p. 280 of present report, where the names outer Defiance ridge and inner Defiance ridge are applied.

Record of drift beds in gas boring at Butler, Ind.

	Feet.
Hardpan (till)	15
Gravel and coarse sand	275
Quicksand, red	40
Clay, compact	45
Cobblestones and bowlders	3
	378

Most water wells in the vicinity of Butler obtain their supply from depths of 20 to 35 feet, though a few of them go down 150 feet. In the northern part of the county, 6 or 8 miles northwest from Butler, wells penetrate till for 60 or 80 feet before striking water-bearing gravel or sand. A well 3 miles south of Hudson penetrated 75 to 80 feet of till.

At Waterloo the drift at the gas well is as follows:

Record of drift in gas well at Waterloo, Ind.

	Feet.
Till	40
Sand and gravel, with water	270
Clay, blue, with pebbles	45
Gravel and cobble	10
	365

At Auburn two gas wells each penetrate about 280 feet of drift, which is largely till in its upper half and largely sand and gravel in the lower half.

A few shallow flowing wells in the vicinity of Auburn on low ground on the border of Cedar Creek obtain water from gravel below the till. The head is seldom more than 2 to 5 feet above the surface.

The gas-well boring at Garrett penetrated about 50 feet of till, 200 feet or more of sand, and a thin bed of gravel at the bottom. The sand and gravel afford a large amount of water. In Garrett many wells obtain water at 40 feet, but some go down 75 to 100 feet. North and west from Garrett are extensive marshes with sandy borders, where wells are obtained at slight depth without entering the till.

Along the Cedar Creek valley, in the southern part of Dekalb County, water is usually obtained at 30 to 40 feet. The wells penetrate more gravel than till, though both are present.

A well 110 feet deep, in the southeastern part of the county near the village of St. Joe and but a few rods from the bank of the river, is mainly through sand and gravel.

A well on the farm of Christian Hirsh, east of St. Joseph River, near Spencerville, has the following section. In the same neighborhood perhaps a dozen other wells go down 60 to 100 feet, mainly through till.

Record of well near Spencerville, Ind.

	Feet.
Till, yellow	10
Till, blue	59
Sand, fine	120
Gravel	9
	198

Whitley County.—The Columbia City gas-well boring penetrated 224 feet of drift, mainly sand. A farm well on the plain in the southeastern part of the county reached a depth of 202 feet without striking rock. It penetrated 67 feet of clayey till, below which for 130 feet were alternations of sandy gravel with beds of till. Water is from gravel at bottom. In the southeastern part of the county the wells pass through a general coating of till 50 to 60 feet thick to strike a good supply of water; many of them are 60 to 80 feet in depth. Along the Eel River valley, however, there is a strip of gravel and sand in which wells obtain water at about river level.

Allen County.—In Allen County, of which Fort Wayne is the county seat, the drift is probably more than 200 feet thick on the northern border but decreases to about 75 feet at the southern

border and in places to 20 or 30 feet; throughout the southern half its general thickness is 75 to 100 feet. At Fort Wayne it is 60 to 125 feet or more. The surface portion of the drift is generally a stiff clayey till, the only prominent exceptions being the gravel plain in the northeast part of the county, which connects Cedar Creek valley with the head of Eel River, and the narrow belt along the St. Joseph. In the northwest quarter of the county the till is generally underlain by water-bearing gravel at 25 to 35 feet, so that deep wells are unnecessary. In the northeastern part the till is thicker and many wells go 60 to 75 feet to the first water-bearing gravel. From Fort Wayne eastward past New Haven a few wells are sunk to rock at 80 feet or less, but others draw from gravel beds between till sheets at 25 to 35 feet. In the old outlet of Lake Maumee, which leads past Fort Wayne to the Wabash at Huntington, there is sand and silt in places, though parts are floored with bowldery till. In the southeastern part of the county gravel beds within the drift furnish water at 30 to 40 feet or less, and in the southern and southwestern parts water-bearing gravel in many places underlies till at 20 or 30 feet. On the Wabash moraine, in the southern part of the county, many wells reach depths of 75 to 100 feet, but on the plain east of it few exceed 50 feet.

Flowing wells may be obtained along Maumee River from Fort Wayne eastward past New Haven. There are already one or more in Fort Wayne. The waterworks at New Haven is supplied from a flowing well 300 feet deep, which draws from rock, the drift being only 82 feet deep.

Adams County.—In Adams County, which lies south of Allen, the moraines and the plain tracts present a nearly continuous sheet of clayey till, there being little or no gravel outwash from the moraines and few gravel knolls. As a rule the drift is thin with a general depth of about 50 feet; where it is thick considerable sand and gravel is found in its lower portion. The great depth of the buried valleys in this region is shown by a gas-well boring at Geneva, which passed through 350 feet of drift, although, within a mile of the boring, rock outcrops at an altitude as great as the well mouth. In this boring the upper 80 feet was mainly through till; and the remaining 270 feet mainly through sand and gravel. Although the surface of the drift, throughout the county, is mainly till, wells show that water-bearing gravel is widespread beneath it at depths of 20 to 50 feet.

Wells County.—Wells County, which lies west of Adams and south of Allen counties, has a somewhat uniform sheet of clayey till at surface, with thin beds of sand or sandy gravel included in or underlying it. The average thickness of drift for the county probably does not exceed 50 feet, and rock is common at 30 to 50 feet.

Huntington County.—Huntington County, which lies west of Allen and Wells counties, has comparatively thin drift south of Wabash River, a depth of 100 feet being encountered in few wells. Northward from the Wabash the thickness increases to fully 200 feet on the northern border of the county. Clayey till forms the surface of the county, but gravel or sand prevails near the base of the drift and occurs as local beds in the till, causing neighboring wells to differ greatly in section. Flowing wells are obtained along the Salamonie Valley in the vicinity of Warren at depths of 65 to 100 feet. All are reported to derive their supply from limestone, but water is decidedly chalybeate, and drift water may have access.

Wabash County.—Wabash County is very similar to Huntington, which it adjoins on the west, both as regards the drift structure and the thickness. The northern end has very thick deposits, probably exceeding 300 feet, the thickness at North Manchester, in the Eel River valley, being 274 feet. The thickness in the southern portion probably averages less than 100 feet, but is much greater in the buried valleys, in one of which, at Lafontaine, it measured 300 feet. The only gravelly districts worthy of note are in narrow strips along the valleys of Wabash and Eel rivers. The till on the Mississinawa morainic system in places extends to depths of 100 feet or more, though usually water-bearing gravel and sand is found within 50 feet of the surface. Near New Madison, in sec. 11, T. 29 N., R. 7 E., a well passed through 160 feet of till and struck rock at 181 feet, and in sec. 26 two others penetrated similar amounts of till. On the plain west of the moraine most wells penetrate till for 25 feet or more before striking gravel or sand.

Grant County.—In Grant County, which lies south of Wabash and Huntington counties, the surface portion of the drift is a clayey till. West from the Mississinawa system the drift is thin, often but 20 feet or less in depth, but from that system eastward the thickness generally exceeds 100 feet and may average 150 feet. In the preglacial valleys it is 300 feet. Where the drift is thick the deeper portions are often largely of sand and gravel.

Blackford County.—In Blackford County, as in northeastern Grant County, the drift is 100 to 150 feet thick. In the northeast corner, however, over a few square miles along Salamonie River, it is but 20 or 30 feet thick. The main part of the drift is a clayey till, but beds of sand and gravel at various depths supply water for the wells. The deeper borings show thin beds of sand in the till.

Jay County.—Jay County, which lies east of Blackford and extends to the Ohio State line, is traversed by the Mississinawa and Salamonie moraines. The former is very largely of clayey till and the latter carries gravel knolls only locally. North of the Salamonie moraine the drift is thin, with rock at 10 to 20 feet. The drift is only 30 to 60 feet in the vicinity of Portland, the county seat, which stands between the two moraines. Along the moraines its thickness probably averages about 100 feet. In preglacial valleys it reaches a depth of about 350 feet. Where thickest and especially in the preglacial valleys its lower part is largely sand and gravel.

CHAPTER IX.

MORAINIC SYSTEMS AT HEADS OF LAKE MICHIGAN AND SAGINAW BASINS.

By Frank Leverett.

KALAMAZOO MORAINIC SYSTEM OF LAKE MICHIGAN LOBE.

ERRONEOUS CORRELATION.

Investigations pursued since the publication of Monograph XXXVIII have shown that certain moraines in southwestern Michigan which were assigned therein to the Saginaw lobe were really produced by the Lake Michigan lobe. The principal errors of interpretation are found on pages 340 to 342 and Plate XV of that monograph. Certain constituents of the drift and the relation of till plains to moraines in the district immediately east of the Valparaiso morainic system led the writer astray in the interpretation of the border between the Saginaw and the Lake Michigan lobes. Later studies have shown that a prominent morainic system, the Kalamazoo, which lies farther east than the border outlined in Monograph XXXVIII was formed by the Lake Michigan lobe. Under the old interpretation the Kalamazoo morainic system was considered a northward continuation of the Maxinkuckee moraine of the Saginaw lobe, but really it is correlated with a younger morainic system of that lobe, connecting with it a few miles north of Kalamazoo, Mich. The writer regrets that so serious an error was introduced in this earlier publication.

COURSE AND DISTRIBUTION.

The Kalamazoo morainic system of the Lake Michigan lobe connects with its correlative of the Saginaw lobe in southwestern Barry County, Mich., 15 to 20 miles northeast of the city of Kalamazoo, the village of Prairieville being in the head of the reentrant angle between the two lobes. The Kalamazoo system embraces two well-defined ridges separated by a nearly continuous but very narrow gravel plain. Each ridge has a general width of about 2 miles but varies in width from 1 mile or less to 4 miles. The combined width of the two ridges and of the gravel plain which separates them is 5 to 7 miles. It is this combined belt that constitutes the Kalamazoo morainic system.

The outer or eastern ridge leads from Prairieville south-southwestward to the Kalamazoo Valley, which it crosses about 5 miles north of the city of Kalamazoo, with an interruption of fully 2 miles. From the west bluff of the river the ridge continues southwestward, passing between Kalamazoo and Brownells station and just west of Oshtemo. It cuts the southeast corner of Van Buren County and passes just west of Marcellus in Cass County and through Cassopolis. It leaves Michigan in the southwest corner of Cass County and extends nearly to the city of South Bend, Ind., where it is interrupted by a broad gravel plain on St. Joseph River.

In Michigan the inner ridge is nearly parallel with the outer. Its inner or western border from Mattawan to Niles is followed by the Michigan Central Railroad. It crosses St. Joseph River near Niles and after doubling back into a bend of the river west of that city goes southward into Indiana and is distinctly traceable as far as the village of Warren, about 6 miles west of South Bend.

Neither of the moraines has been identified with certainty farther south and west. Certain features, however, suggest that the line of continuation is westward past Rolling Prairie to the vicinity of Laporte, beyond which the Kalamazoo is thought to be entirely concealed

by the Valparaiso morainic system, unless perchance it is represented in what has been considered the outer portion of that system in northwestern Indiana and northeastern Illinois. One feature which suggests its westward continuation from South Bend toward Laporte is the bowldery, somewhat undulating gravelly district known as Rolling Prairie, which lies east of the station of that name and which stands above the level of the neighboring portion of the Valparaiso system and of the outwash apron connected with that system. Another feature is the great gravel plain which lies north of the Kankakee Marsh in Laporte and Porter counties, Ind., at a level higher than that of the lines of glacial drainage which head in the Valparaiso morainic system and lead through this plain. The plain appears to be older than that connected with the Valparaiso morainic system and to be composed of outwash from an ice border which is largely concealed, as above suggested, by the extension of the Valparaiso system. The altitude near New Carlisle and westward from there to Laporte is 50 to 75 feet above the gravel plains that head in the Valparaiso morainic system.

It is possible that the Kalamazoo system embraces a bowlder-strewn gravel tract known as Sumption Prairie, which lies south of the head of Kankakee River just west of the city of South Bend, but with this exception it seems to lie entirely north of the Kankakee. Aside from basins both Sumption and Rolling prairies have nearly plane surfaces, and both seem to be composed entirely of assorted material capped with a bowlder-strewn loamy deposit a few feet thick. Were it not for the large number of bowlders these tracts would naturally be classed as outwash aprons, and they seem on the whole to be more closely allied to outwash than to moraine.

The great width of the gravel plain on the north side of the Kankakee east of the meridian of Valparaiso may be best explained on the interpretation that the plain was built up by the Lake Michigan lobe in the course of a recession across the area thus covered, and that it buried any morainic features which may have developed during the recession. From the meridian of Valparaiso westward into Illinois, though there is very little outwash between the morainic system and the Kankakee Marsh or between the different members of the morainic system, the bulk of the morainic system is fully as great as the combined bulk of the moraines and gravel plains on the north side of the Kankakee east from Valparaiso and of the combined Kalamazoo and Valparaiso morainic systems in southwestern Michigan. It may, therefore, as above suggested, embrace both the Kalamazoo and the Valparaiso morainic systems, though as yet the two have not been differentiated in that region.

TOPOGRAPHY.

ALTITUDE.

The Kalamazoo morainic system appears to attain its greatest elevation in the immediate vicinity of its junction with the correlative morainic system of the Saginaw lobe near Prairieville, Mich., where its altitude is about 1,050 feet above sea level; at only a few points, however, does it rise above 1,000 feet. The altitude of the outwash apron at Prairieville is nearly if not quite 1,000 feet. The crest of the outer ridge throughout much of its course from Prairieville to the Michigan-Indiana State line is between 900 and 1,000 feet, though for a few miles near the State line it does not quite reach 900 feet. The inner ridge has a crest above 900 feet as far southwest as the vicinity of Dowagiac, but from that city southwestward to the State line it exceeds 800 feet at few points. The highest points on the bowlder-strewn Rolling Prairie and on the neighboring portions of the gravel plain in Laporte County, Ind., are about 825 feet, but the crest of the morainic system in northwestern Indiana in few places rises above 800 feet and in some places drops to about 700 feet.

RELIEF.

The outer border of the morainic system shows comparatively slight relief, for the gravel plain which follows it for its entire length from Prairieville to South Bend has been built up nearly to the level of its crest. Nor does either morainic ridge show more than slight relief

above the gravel plain which lies between them, except in the district from Dowagiac southwest to St. Joseph River, where the inner ridge and the gravel plain drop nearly 100 feet below the crest of the outer ridge. The relief on the inner or western border of the inner ridge is about 200 feet throughout its entire course from Barry County to Dowagiac, the plain west of the ridge being about 750 feet and the ridge nearly 950 feet, but from Dowagiac to Niles the relief on this border is reduced to about 50 feet and it exceeds 75 feet in but few points in the tract west of St. Joseph River.

CHARACTER.

Outer ridge.—Along the entire length of the outer ridge, basins as well as sharp knolls are conspicuous. Many of the knolls stand 50 to 75 feet above the neighboring basins, but only 25 to 50 feet above the bordering outwash apron, below which many basins are sunk 25 feet or more. Many of the basins are occupied by ponds or small lakes, though most of them are either dry or have been sufficiently filled to be largely occupied by vegetation. The gravel plain between the two ridges contains a number of lakes, some of which are one-half mile or more in width and nearly fill the space between the ridges. The great majority, however, are only a few acres in extent and some are but a fraction of an acre. On the west border of the outer ridge for a few miles in the southwest portion in Cass County, Mich., and St. Joseph County, Ind., there is a steep bluff 50 to 100 feet in height which apparently was produced by border drainage along the front of the ice when it had receded a short distance west of the moraine. Elsewhere the inner or west face of the outer ridge carries knolls and basins down to the level of the gravel plain which separates it from the western ridge. In places in the vicinity of the State line the outwash apron extends back into the ridge for a mile or more, and in a number of places basins occupied by small lakes cause slight irregularities, but as a rule the front of the moraine is remarkably regular.

Inner ridge.—The inner or western ridge is much more broken by deep depressions than the outer. These depressions open westward into the inner border district, which, as already stated, is nearly 200 feet lower than the crest of the ridge. The eastern border of the ridge, however, shows only slight irregularity, and the basins are usually only 25 to 35 feet below the level of the gravel plain between the two morainic ridges. The inner ridge has its greatest width immediately northeast of Dowagiac, where narrow gravel plains associated with the moraine lead to the larger gravel plain outside. Immediately south of Decatur the gravel plain for 2 or 3 miles virtually takes the place of the inner ridge, being built to a level nearly as high as the neighboring parts of the moraine.

A conspicuous depression or fosse, one-fourth to one-half mile wide and 20 to 25 feet deep, lies between the inner ridge and the gravel plain immediately east and south of Dowagiac. The gravel plain stands like a bluff on the southeast border of this fosse or depression, but the ridge on the west is very inconspicuous, few of its knolls being more than 10 or 15 feet in height and its crest being scarcely as high as the gravel plain.

The inner ridge in the bend of St. Joseph River west of Niles reaches an altitude only a few feet higher than that of the gravel plain on its south border, but knolls in it are 30 to 40 feet above neighboring sags and basins. It is much broken by basins near the State line and southward to Warren, Ind. Several of the basins contain lakes. The knolls are rather sharp or steep sided throughout this section west of St. Joseph River. On its western or inner face near Buchanan, Mich., a steep bluff 30 feet or more in height has been formed, apparently by border drainage. The ice approached this place very closely while forming the Valparaiso morainic system. Whether the cutting of this bluff occurred immediately on the withdrawal of the ice from the Kalamazoo system or at a later time during the development of the Valparaiso system, has not been clearly worked out.

The topography of Sumption and Rolling prairies, as already indicated, is more like that of the neighboring gravel plains than of the Kalamazoo morainic system. Basins are conspicuous, but knolls and ridges of strong expression are wanting. In places a slight undulation of surface is visible, but it amounts to scarcely 15 feet in vertical range.

One isolated knoll 3 miles east of Laporte in sec. 33, T. 37 N., R. 2 W., rises about 50 feet above the bordering gravel plain and reaches an altitude of 850 feet above sea level. It is separated from Rolling Prairie by the valley of Little Kankakee River.

STRUCTURE OF THE DRIFT.

COMPOSITION.

Throughout the length of both ridges of the Kalamazoo system the drift is mainly assorted material of various grades of coarseness. There is at surface either a loose-textured stony clay or a sandy drift, everywhere carrying a liberal supply of bowlders. On some of the sandiest knolls bowlder piles may be seen in the cultivated fields, and on many of the clayey ones bowlders are so numerous as seriously to hinder cultivation. The general thickness of the capping of bowldery clay is only a few feet. Loose sand and gravel is reported to underlie wide areas at a depth of less than 10 feet. In places a brown or blue clayey till underlies the looser-textured or more stony surface clay: and in places clayey till is struck at moderate depths beneath sand and gravel in both the morainic system and the outwash tract east of it. But the general prevalence of thick beds of sand and gravel is shown by numerous well records, supplemented by natural exposures near streams and on the edge of the basins of the small lakes.

THICKNESS.

Some wells have reached depths of over 200 feet without penetrating much till or striking bedrock. Some of the deepest wells are found on the border of the Kalamazoo Valley and northward from there into the interlobate spur north of Prairieville. From Kalamazoo southwestward most wells are only 75 to 80 feet deep, though a few are 150 to 160 feet.

In sec. 15, Rutland Township, Barry County, J. Belson bored to a depth of 210 feet from an altitude of about 870 feet without striking rock. Water was found at about 100 feet and the well completed to that depth, the lower part of the boring being through fine sand that did not increase the yield of water.

In sec. 11, Orangeville Township, Barry County, a well made by Mr. Stewart on ground about 975 feet above sea level reached a depth of 150 feet and was entirely through sand and gravel after passing through 10 feet of brown stony clay at the surface. Water was found only in the lower 20 feet. In the vicinity the brown stony surface clay was found to range in thickness from 3 feet up to 16 feet or more, the greatest thickness being in basins. Several wells have reached depths of 150 feet or more without encountering any till except that at the surface.

In sec. 28, Orangeville Township, two wells, starting at an altitude of about 950 feet and having depths of 208 and 196 feet, are reported to have been in sand and gravel after passing through the thin surface bed of brown stony clay.

Near Prairieville some wells 75 to 100 feet in depth have penetrated thin beds of blue clay at about 30 feet from the surface as well as 6 to 8 feet of the brown surface clay. A well in sec. 15, Prairieville Township, penetrated reddish-brown till 10 feet, sand 20 feet, gravel 30 feet.

A well in sec. 1, Cooper Township, Kalamazoo County, on the farm of Mr. Haskins, is 120 feet in depth and shows scarcely 20 feet of clay. A well near by penetrated 40 feet of brown stony till and 43 feet of dry sand, obtaining water in gravel at the bottom. A well in the south part of the same section on the crest of the outer ridge of the Kalamazoo system at an altitude of about 975 feet penetrated alternations of gravel and very stony till throughout its entire depth of 130 feet. Another well 100 rods west, on somewhat lower ground, penetrated reddish-brown till 30 feet, sand 40 feet, reddish brown till 25 to 30 feet, and water-bearing gravel 8 to 10 feet.

On the west side of Kalamazoo River, in southern Cooper Township, several wells on the outer ridge of the Kalamazoo system are 100 to 160 feet in depth and are largely through sand

and gravel. A well on the inner ridge in sec. 7, Cooper Township, penetrated 60 feet of sand and gravel and 20 feet of blue clay; it obtains water from the gravel.

In southeastern Alamo Township, Kalamazoo County, on an elevated part of the inner ridge, three wells have penetrated 175 feet largely through sand and gravel and found water only in the lower 50 or 60 feet. The deepest well in the township and perhaps along the whole course of the moraine is that of J. Coshan in sec. 33, which reached a depth of 230 feet on ground about 965 feet above sea level. It penetrated reddish sandy clay and dry sand 20 feet, blue clay 1 foot, white sand 120 feet, bluish water-bearing sand 85 feet, coarse white sand 5 feet. A neighboring well in sec. 28 on the McCall farm, 153 feet deep, penetrated yellowish sand and sandy clay 50 feet, blue clay 10 feet, gray sand 93 feet.

Some wells in the northwestern part of Kalamazoo Township penetrate till to 30 feet or more and then dry gravel to about 100 feet. Several wells are 110 to 120 feet deep. The water has a head about 100 feet below the surface.

On a prominent part of the inner ridge south of Lawton at an altitude of about 930 feet several wells 145 to 160 feet in depth penetrated some till in the lower part as well as a few feet of surface till. A dug well in sec. 8, Porter Township, 100 feet in depth, penetrated a hard clayey till in the lower 35 feet. South of this well, in sec. 17, several tubular wells obtain water at about 60 feet, presumably at the top of this clayey till.

Between Lawton and Dowagiac several wells, both on the inner ridge of the Kalamazoo system and on the gravel plain just outside, have reached depths of 100 feet or more, largely through sand and gravel. Most wells on the outer ridge from the vicinity of Lawton southwestward obtain water at depths of 75 to 80 feet and penetrate but little clayey till. In the low portion of the inner ridge, between Dowagiac and Niles, wells are very largely in sand and gravel, but obtain abundant water at 40 to 50 feet. On the ridge west of Niles many wells reach 80 or 100 feet, some of them penetrating considerable clayey till. As a rule, however, the wells in this section of this moraine and especially in the Indiana portion encounter little besides sand and gravel after penetrating a few feet of surface clay.

On Rolling Prairie many wells are driven to depths of 75 feet or more through sand and gravel, but on Sumption Prairie they obtain water at depths of 50 to 60 feet. In both districts the water table seems to be nearly down to the level of the Kankakee Marsh.

OUTWASH.

DISTRIBUTION IN MICHIGAN.

The outwash district connected with the Kalamazoo morainic system of the Lake Michigan and Saginaw lobes is one of the most extensive in Michigan, for the outwash fills nearly all the space between the Kalamazoo morainic system and neighboring earlier ones. From the reentrant angle between the lobes in southwestern Barry County a gravel plain descends continuously southward across the valley of Kalamazoo River to the St. Joseph Valley, and this constituted the most vigorous line of discharge from the ice border. Outwash aprons lie all along the eastern side of the outer moraine of the Kalamazoo system except for a short interval of 2 or 3 miles in the vicinity of Wakelee, where the moraine approaches an earlier one so closely that only a narrow line of glacial drainage separates them. The width of the outwash tract is measured by the distance between the outer moraine of the Kalamazoo system and the moraine outside; it is about 15 miles throughout much of Kalamazoo County but is only 1 to 5 miles in Cass County, Mich.

SLOPE.

At the head of the reentrant in the vicinity of Prairieville the altitude of the outwash apron is about 1,000 feet, but within a few miles south it drops to about 950 feet. The altitude is nearly 950 feet along much of the western border in Kalamazoo County and remains above 900 feet as far southwest as the vicinity of Cassopolis, but falls to about 800 feet where it joins the gravel plain of St. Joseph Valley north of South Bend. The altitudes just given pertain to the portion of the outwash apron that fits against the moraine; within a mile or

two east from the moraine they drop 25 to 30 feet and within a few miles they drop 50 to 75 feet. The water probably ran down the slope eastward and southeastward directly away from the moraine until it met the trunk stream flowing southward from the reentrant angle between the ice lobes. This stream apparently passed east of the site of the city of Kalamazoo and continued southward past Vicksburg, reaching the St. Joseph Valley between Mendon and Three Rivers. The southward slope of the portion of the plain traversed by the trunk stream is indicated by the drainage, streams tributary to the St. Joseph having their sources on the immediate border of the Kalamazoo Valley, and is demonstrated by the following list of elevations:

Elevations on plain leading from reentrant angle.

	Feet.
Prairieville	1,000
Milo	957
Richland	928
North bluff of Kalamazoo	880
South bluff of Kalamazoo	875
Vicksburg	857
Moore Park	841

A definite bluff 15 to 50 feet high on the eastern side of the gravel plain from Kalamazoo River southward to St. Joseph River puts this border in decided contrast to the western border, which grades upward into the moraine. Possibly this bluff was cut by border drainage before the ice had receded to the position of the outer ridge of the Kalamazoo morainic system, for the wide extent of plain over which the waters were free to flow after the ice had receded to that system would seem to leave no necessity for the stream to crowd its eastern bluff. The altitude of the plain for several miles west from this eastern bluff seems also to correspond closely to that of the base of the bluff, so that no reason for crowding is to be found in the slope of the eastern portion of the plain.

BASINS AND CHANNELS.

Basins are very numerous on this outwash tract on the immediate border of the outer ridge of the Kalamazoo morainic system but are scarce out in the midst of the plain; most of them are large, an area of a square mile or more being not uncommon. North of Kalamazoo River they are numerous both on the border of the ridge and in the plain. Their wide distribution is somewhat surprising and seems to indicate that the development of the Kalamazoo system followed closely on the recession of the ice border, there being insufficient time for the large detached masses of ice left in the course of the recession to become entirely melted before the filling of outwash from the Kalamazoo system was completed.

In the vicinity of Kalamazoo several conspicuous valley-like depressions lead from the border of the system eastward to the Kalamazoo Valley. They are about 50 feet below the neighboring parts of the gravel plain and are one-eighth to one-fourth mile in width. At the western or morainal end they head very abruptly, as if cut by a waterfall. Their beds are not graded to a uniform slope but contain basins and other inequalities, which, however, may be no greater than would result from the rush of a strong current of water. One valley is followed by the main line of the Michigan Central Railroad for about 2 miles from the western part of the city of Kalamazoo. Others lie both to the north and to the south. The longest heads in Crooked Lake in sec. 15, Texas Township, about 10 miles southwest of Kalamazoo, leads northeastward, and opens immediately south of the city into a part of the gravel plain corresponding in elevation with its bed. These valley-like depressions are thought to indicate that the discharge from the ice border became localized on certain lines toward the close of the development of the moraine and began to cut instead of fill. While the waters were issuing in shallow sheets all along the edge of the ice they would naturally lay down their earthy burden promptly and would aggrade the region, but they could hardly do this when they flowed along restricted lines, especially if in considerable volume. This feature is met with in gravel plains elsewhere, though it is by no means common.

FEATURES IN INDIANA.

In the district west of St. Joseph River a gravel plain, with an altitude of 800 feet on its north border near Niles, Mich., slopes slightly to the south or southeast from the edge of the moraine. Between the inner moraine of the Kalamazoo system and the Rolling Prairie bowldery tract a lower gravel plain known as Terre Coupee Prairie, an outwash from the Valparaiso morainic system, drops from an altitude of about 775 feet where it fits against the moraine to about 700 feet at the edge of the Kankakee Marsh. The Rolling Prairie gravelly tract west of the Terre Coupee Prairie has an altitude of about 850 feet immediately south of New Carlisle but drops to less than 800 feet on its southern border. Between the Rolling Prairie bowldery tract and Laporte another low gravel plain, heading in the Valparaiso morainic system at an altitude of about 780 feet, leads down the Little Kankakee to the Kankakee Marsh. The plain west of it, on which the city of Laporte stands, has an altitude of about 810 feet next to the moraine but drops to 740 feet within about 8 miles southeast of Laporte, and maintains a similar slope toward the Kankakee through its entire breadth in Laporte and eastern Porter counties. This plain is trenched by shallow valleys through which the waters of the Valparaiso system found discharge; one of them is occupied by Mill Creek and another by Crooked Creek.

COMPOSITION OF THE OUTWASH.

Along the border next to the morainic system the outwash material is much coarser than it is at a distance, as it would naturally be if the plain was formed by waters issuing from the ice sheet. Stones several inches in diameter are abundant for about a mile from the moraine, but at greater distances few exceed 3 inches and most of the material is a fine gravel with considerable sandy admixture. Portions of the plain have a capping of 2 or 3 feet of reddish clay, which appears to be more prevalent on the high part of the gravel plain in the reentrant between the Saginaw and Lake Michigan lobes and along the border of the Kalamazoo system in southwestern Kalamazoo County than it is in the lower and more sandy portions of the plain in central and southern Kalamazoo County. Owing to the clayey character of the soil, portions of the plain in southwestern Kalamazoo County are timbered with beech and maple; yet the clay in few places reaches a depth of 5 feet and it is everywhere underlain by coarse outwash material.

The thickness of the outwash material on the high parts of the gravel plain in western Kalamazoo County and in the reentrant angle in northern Kalamazoo and southwestern Barry counties is only 30 or 40 feet, for many wells enter till within 40 feet of the surface. Till is also exposed in the cuts along the main line of the Michigan Central Railroad west of Kalamazoo to within 40 feet of the level of the gravel plain. East of Kalamazoo in the district south of the valley of Kalamazoo River the gravel is very thin and in places till comes to the surface; this is in the line of the main discharge of water southward from the reentrant angle between the ice lobes. Many of the basins on the gravel plain appear to be as deep as the gravel and to be underlain by clay. On the whole, wells in this outwash tract show a larger amount of till than is found in the moraine. The till seems to be of a clayey texture similar to that east of the gravel plain in southeastern Kalamazoo County.

C. W. Jones's well at Richland, 120 feet in depth, penetrates red clay 3 feet, sand and gravel 40 feet, fine quicksand 3 feet, blue till 70 feet, coarse sand with water 4 feet. D. R. Chandler's well, a mile south of Richland, 152 feet in depth, has blue till in its lower 100 feet. Two other wells in Richland were reported to strike blue till at about 45 feet. A well 45 feet deep in sec. 35, Prairieville Township, Barry County, 3 miles north of Richland, was in blue till in the lower 17 feet. Several wells in the southern part of Richland Township and the northern part of Comstock obtain water at the top of a blue till beneath 50 to 60 feet of outwash material.

At Kalamazoo a boring for gas made in 1887 reached rock at 130 feet. At the waterworks several borings about 120 feet in depth do not reach rock. None of the borings penetrated much till, the greater part of the drift being a fine sandy gravel. All are in the valley of Kalamazoo River at an altitude of about 775 feet, or 150 feet below the high part of the gravel plain west of

the city. It is not improbable that the rock surface is as low beneath the gravel plain as in the valley, and if so the drift may be about 300 feet thick in the highest part of the gravel plain.

INTERMORAINIC GRAVEL PLAIN.

The gravel plain between the two ridges of the Kalamazoo morainic system has a general width of about a mile, but in places it is nearly or quite pinched out by protrusions of the inner toward the outer ridge. Its continuity is further broken by basins which fill it almost from side to side. It furnishes, however, a continuous line of glacial drainage from the head of the east branch of Dowagiac River in southeastern Van Buren County, Mich., to the St. Joseph Valley at South Bend, Ind. It descends gradually from about 930 feet near the head of the Dowagiac to 850 feet at Lagrange, Mich. (where the stream leaves the gravel plain to run northwest into the west branch), to about 775 feet east of Niles, and to 750 feet or less to the St. Joseph plain near South Bend.

Some difficulty is found in interpreting the direction of discharge in the part of the gravel plain north of the head of the east branch of Dowagiac River. This northern portion nowhere appears to exceed 950 feet, and in the vicinity of Kalamazoo River is only about 930 feet, or as low as at the head of Dowagiac River. One section of the gravel plain about 14 miles in length, which is cut about midway by the main line of the Michigan Central Railroad, may have found discharge eastward through the eastern ridge at a gap occupied by Crooked Lake and thence northeastward along the valley cut in the gravel plain. This section is shut off from East Dowagiac River on the southwest by a protrusion from the western ridge east of Lawton, and is bordered on the north by a prominent ridge that runs eastward toward Brownells station. Between this last ridge and another projection of the western moraine, which extends southeastward from Alamo to Brownells, is a small gravel plain occupying about 2 square miles whose altitude is 950 feet and whose line of discharge was probably through narrow sloughs that cross the eastern ridge near Brownells. Near Cooper a gravel plain on the west side of the Kalamazoo, standing about 930 feet above sea level, probably drained southeastward past Kalamazoo. The portion north of Kalamazoo River is likely also to have drained southeastward.

So far as can be ascertained from well records, the gravel plain between the two ridges of the Kalamazoo morainic system is underlain throughout its entire length by very thick deposits of gravel and sand; at least it has so far furnished no evidence of blue till at moderate depths, and it thus contrasts with the outwash apron outside the outer ridge.

KALAMAZOO VALLEY.

In traversing this outwash district from near Galesburg to Kalamazoo, the Kalamazoo Valley leads directly across the line of glacial drainage and then turns northward in a direction opposite to that of the glacial drainage. Under ordinary conditions one would expect the modern drainage to turn southward along the line of the glacial drainage, especially if the district outside the Kalamazoo morainic system was graded up to a southward slope. The size of this portion of the Kalamazoo Valley is also remarkable, being 1½ to 2 miles wide and about 100 feet deep throughout its course across the outwash district. The valley also is characterized by irregularities not easily referred to drainage erosion, there being recesses in the bluffs and ridgings along the slopes that seem better explained as the result of glacial action. The course of the valley, its great size, and the irregularities of its bluffs suggest the persistence of a mass of stagnant ice along its course during the deposition of the outwash gravel. The subsequent melting of the ice would leave this belt, traversed by the river, lower than the bordering districts and would thus determine the course of drainage. Gull Lake, a few miles northeast of Kalamazoo, is in a large basin which is like that postulated for this section of Kalamazoo River but which did not fall within reach of a river.

A conspicuous feature of the valley is a broad terrace on the east side of the river immediately north of Kalamazoo. It stands about 850 feet above sea level, or a few feet below the level of the gravel plain that extends southward from Kalamazoo River. It seems to have been formed

by northward rather than southward drainage. This terrace has no continuation beyond the Kalamazoo morainic system, the country west of the latter being much below its level. In explanation of this high terrace it seems necessary to assume a barrier of some sort below its position. Possibly the morainic accumulations in the valley were sufficient to hold the river up to this level during the development of the terrace. It seems quite as probable, however, that the ice sheet did not entirely melt away until the terrace had been formed. Opposite this terrace the slopes are very irregular, as if ice might have persisted during their development and have thus prevented their smoothing over by the stream. Some evidence of such ice persistence is cited below in the discussion of the Kendall moraine (p. 183).

INNER BORDER.

INTERPRETATION.

The narrow strip between the inner or western morainic ridge of the Kalamazoo system and the Valparaiso morainic system is by no means easy to interpret. The portion from Paw Paw northeastward to the Kalamazoo Valley is especially complex, and it was here that the writer was led astray (see p. 174) in the interpretation presented in Monograph XXXVIII. The outer part of the Valparaiso system from Paw Paw southwestward to the State line and beyond is marked by a strong ridge with a regular border, outside of which is a nearly parallel outwash apron that fills much of the space between it and the inner moraine of the Kalamazoo system, from which it is clearly separable.

In the interval from Paw Paw northward to the Kalamazoo Valley in at least two places the Kalamazoo and Valparaiso systems seem to be connected by weak cross ridges, which suggest that the ice border persisted here in its occupancy of the inner face of the Kalamazoo morainic system, while it withdrew several miles from it in the district southwest from Paw Paw and began the development of the strong outer ridge of the Valparaiso system. Aside from these two weak cross ridges there is, in the northeastern township of Van Buren County, a conspicuous drift aggregation which is not easy to correlate with neighboring moraines. There are also conspicuous swampy channels which appear to mark courses of glacial drainage. The intervening tracts not embraced in ridges or in channels are largely sandy and plane surfaced, the only till plain noted being in the southern edge of Allegan County.

An inconspicuous, gently undulating, bowldery strip parts from the Kalamazoo system about 8 miles west of Kalamazoo and passes southwestward to South Fork of Paw Paw River at Paw Paw, nearly opposite the terminus of a strong ridge of the Valparaiso system. Its swells are only 10 to 15 feet high and have very gentle slopes, and its weakness is strikingly in contrast both with the strong moraine of the Kalamazoo system from which it separates and with the bulky moraine of the Valparaiso system with which it may connect at Paw Paw. Bowlders are less numerous on it than on the strong moraines just mentioned. Its soil is sandy and no clayey drift is reported in wells having depths of 40 or 50 feet. On the south side of this undulating strip is a sandy plain, which may perhaps be an outwash apron for it slopes gently southward to the west-flowing portion of the South Fork of Paw Paw River.

Two correlations are possible at the west end of the undulatory strip, one being found in a chain of knolls and short ridges that leads southwestward past Decatur into the northwestern part of Cass County, and the other in a strong morainic ridge of the Valparaiso system that sets in on the west side of South Fork of Paw Paw River just north of Paw Paw. The most prominent knoll in the first-named chain is about a mile south of Paw Paw and has a height of nearly 150 feet above the village and about 100 feet above the bordering plains. Elsewhere the knolls are only 10 to 20 feet high and are separated by plane tracts of considerable width. Most of the knolls carry bowlders, but the bordering plains are nearly free from them. It is a question whether this weak and fragmentary chain constitutes an ice-border feature. The knolls may have been formed incidentally in the retreat of the ice from the Kalamazoo to the Valparaiso system and not be definitely related to each other nor to the weak ridge that leads into Paw Paw from the inner ridge of the Kalamazoo system.

North of Kalamazoo River the conditions are again simple (as in the district southwest from Paw Paw), a strong morainic ridge of the Valparaiso system with regular border running northward across eastern Allegan County, and a pitted gravel plain to the east filling in much of the space out to the inner ridge of the Kalamazoo system.

KENDALL MORAINE.

A few miles north of Paw Paw lies a prominent ridged belt which rises in an outwash apron east of the main part of the Valparaiso system, in the northeastern part of Van Buren County. The village of Kendall is situated on it and the name Kendall moraine has been applied to it. It is provisionally assigned to the Kalamazoo system though it may prove to be as closely related to the Valparaiso system. Its length is about 9 miles and its width 1½ to 2½ miles. The portion north of Kendall is very prominent, knolls 60 to 80 feet in height being present. South of Kendall it is weaker, though a knoll in sec. 31, Pine Grove Township, is 50 feet in height. Ordinarily the knolls in this portion rise only 25 to 30 feet above neighboring sags and basins. Knob and basin topography appears all along the belt, and several of the basins contain small lakes. The surface, especially north of Kendall, is in places very thickly set with bowlders, the largest of which are 8 or 10 feet in diameter. Among them were noted conglomerates of various kinds, including the red jasper conglomerate thought to be derived from the Huronian ledges north of Georgian Bay, a few pieces of gypsum, and numerous limestone fragments derived from Mississippian formations to the north. The drift appears generally to be loose textured though not well assorted. Blue till, if present, lies at considerable depth. A well 202 feet deep on an elevated portion of the moraine in sec. 14, Pine Grove Township, penetrated throughout much of its depth a sandy stony reddish-brown till with a few blue or gray streaks. Considerable blue till was found, however, in a well one-half mile farther east on ground 150 feet lower, which penetrated 8 or 10 feet of gravelly clay and 35 feet of loose gravel and cobble and then went 100 feet into blue till without passing through it.

The Kendall moraine terminates at the northeast in a swamp that is part of a line of glacial drainage which led southwestward from Kalamazoo River to Paw Paw River and which was apparently in operation after the ice had withdrawn. East of this swamp a weak ridge, which may prove to be the continuation of the Kendall moraine, leads northeastward across the northwestern township of Kalamazoo County and connects with the inner moraine of the Kalamazoo system. It is only one-fourth to one-half mile in width and has a gently undulating surface, with a relief on its inner slope of 25 to 50 feet, but with scarcely any relief on its outer slope, the outwash apron being built up nearly to the level of the crest. Bowlders are present on its inner or north slope. Its outwash apron is in harmony with one on the outer border of the Kendall moraine and this perhaps constitutes one of the strongest points in favor of its correlation with that moraine. This correlation of the ridges forms a bridge across the space between the Valparaiso and the Kalamazoo morainic system similar to that near Paw Paw.

WITHDRAWAL OF THE ICE.

Certain features immediately north of the Kendall moraine indicate that the ice withdrew northward from it. Along the slope at the northern end of the prominent part of the moraine, about 125 feet below the crest and about 50 feet above the neighboring swamp, a definite terrace is traceable, running from the middle of the line of secs. 2 and 11, Pine Grove Township, southeastward into sec. 13, a distance of nearly 2 miles, and opening into the outwash apron on the southeast border of the moraine. It seems best explained as having been formed by a line of border drainage running between the ice and the moraine from which the ice had just receded. Within a mile north of this terrace a till plain sets in and a similar till plain is found north of the weak ridge east of the swamp, both of which fit in naturally as ground moraine connected with the terminal moraines just discussed.

On this interpretation the ice held its position along the inner edge of the Kalamazoo morainic system north of Kalamazoo River while forming the Kendall moraine and the weak ridge

that apparently connects it with the Kalamazoo system. Features immediately southeast of Plainwell suggest that the ice may have protruded into the Kalamazoo Valley at the time the Kendall moraine was forming. The weak ridge which leads in from the west seems to wrap around the base of the prominent part of the Kalamazoo system south of Plainwell and to extend southeastward through secs. 5 and 9, Cooper Township, along the west bluff of Kalamazoo River. Possibly this protrusion of the ice into the Kalamazoo Valley may have held the river at the level of the broad 850-foot terrace near Kalamazoo. If so, the stream is likely to have found escape along the ice edge, between the weak ridge just mentioned and the prominent inner ridge of the Kalamazoo system south of Plainwell, into the low country west of the Kalamazoo system.

GLACIAL DRAINAGE.

Considerable complexity marks the glacial drainage. The swamps which occupy the beds of the old lines of drainage can not be connected into a single drainage system. A conspicuous swamp heading just south of Paw Paw is 755 to 760 feet in altitude at its north end and slopes southwestward to about 720 feet at its south end west of Dowagiac, where its bed is expanded into a plain that was apparently occupied by a lake termed Lake Dowagiac (see Ann Arbor folio), which discharged into the Kankakee at South Bend, Ind. This swamp probably was functional as a line of glacial drainage at the time when the ice occupied the weak ridge that leads eastward from Paw Paw to the Kalamazoo morainic system and continued functional until the ice had receded sufficiently to permit the glacial waters to discharge down the Paw Paw Valley.

A second conspicuous swamp heads northeast of the prominent part of the Kendall moraine and leads southwestward down Paw Paw River. This swamp has an altitude of about 725 feet at the divide between Kalamazoo and Paw Paw rivers, east of Kendall, and falls to about 700 feet at the junction of the two forks of Paw Paw River north of the village of Paw Paw. It has cut into the outwash apron bordering the Kendall moraine to a depth of 25 feet or more, indicating that it is somewhat the younger. Evidently the ice must have receded to the north side of Paw Paw River as far down as the edge of Berrien County, or nearly to its mouth, before glacial drainage could have made use of the Paw Paw Valley, and this apparently was considerably later than the time of the formation of the Kendall moraine.

A third swampy belt, north of Kalamazoo River, is followed by Gun River from Gun Lake down to the Kalamazoo. Its altitude is scarcely 725 feet where it is crossed by the Grand Rapids & Indiana Railway north of Plainwell, or a little less than at the northern end of the swamp that leads from the Kalamazoo southward to the Paw Paw drainage. The difference, however, is very slight and it is not improbable that the whole excess is due to peaty accumulations on the divide between Kalamazoo and Paw Paw rivers, in which case the drainage from the Gun River channel may have been continued into the Paw Paw channel.

LAKE MICHIGAN-SAGINAW INTERLOBATE TRACT.

DISTRIBUTION.

The junction between the Lake Michigan and Saginaw lobes during the formation of the Kalamazoo morainic system was in western Barry County, a few miles southwest of Hastings. In the course of the development of the moraines the junction worked northward in a somewhat zigzag course, being for a time in the southern edge of Kent County about 12 miles south of Grand Rapids, later near the site of the city of Grand Rapids, and still later a few miles south of Big Rapids. From Big Rapids north to Cadillac a very massive morainic accumulation was formed, covering the western half of Mecosta County, the eastern part of Newaygo and Lake counties, a large part of Osceola County, and a few miles of southeastern Wexford and southwestern Missaukee counties. This accumulation is more than 50 miles in length and 25 miles in breadth and is by far the most prominent morainic development in the southern peninsula.

TOPOGRAPHY.

ALTITUDE.

Near the northern end of the interlobate tract, about 10 miles southeast of Cadillac, is the highest point in the southern peninsula of Michigan, the precise location being in sec. 12, Sherman Township, Osceola County, and the altitude a little more than 1,700 feet above sea level. A tract of only a few square miles of this moraine, mainly in the area just referred to, rises above the 1,500-foot contour; about 50 square miles in the same region rises above the 1,400-foot contour; and but little more than 100 square miles rises above the 1,300-foot contour. A considerable portion of the massive belt from Big Rapids northward rises above the 1,000-foot contour, but from Big Rapids southward only the crests of the ridges and a few prominent points reach that altitude. The altitude in the vicinity of Grand Rapids is little more than 800 feet on the crests of the morainic ridges and is only about 700 feet on the lower land between the ridges. At the junction of the outer moraine of the Kalamazoo system and its correlative moraine of the Saginaw lobe southwest of Hastings an altitude of about 1,050 feet is attained. The range in altitude along the line of this interlobate tract is thus about 1,000 feet—from 700 feet up to 1,700 feet above sea level. From this interlobate tract there is a general westward descent to the Lake Michigan basin and a general eastward descent to the Saginaw basin. (See Pl. VII.)

RELIEF.

The relief of the massive moraine above the border districts is more conspicuous from Mecosta County northward than it is southward. In eastern Newaygo and Lake counties it amounts to about 300 feet above the plains on the west, and in northern Osceola County it is about as much above the plain around Cadillac. On the eastern border north of Muskegon River it is 300 to 500 feet, but south from that stream it scarcely exceeds 100 feet. From the vicinity of Big Rapids southward it is as much as 100 feet in only the most prominent parts of the morainic system. In the southern part of the system it is most conspicuous in western Barry County near the junction of the Kalamazoo system of the Lake Michigan lobe with the same system of the Saginaw lobe, where the crests of the highest ridges stand about 300 feet above the low plain to the west traversed by Gun River.

CHARACTER.

The interlobate tract is generally of a pronounced knob and basin type of topography, but it includes gentle swell and sag areas of considerable size. One of the most extensive of these lies south of Grand Rapids, where only a few sharp knolls appear throughout an area of perhaps 100 square miles. The portion of the Kalamazoo morainic system between Grand and Muskegon rivers in northern Kent and western Montcalm counties carries only a few prominent ridges and has few knolls that exceed 50 feet in height. A considerable part of the massive moraine in Newaygo, Mecosta, Lake, Osceola, Wexford and Missaukee counties has a very irregular surface with sharp knolls 50 to 100 feet in height, among which are numerous basins. The highest part of the moraine, where an altitude of 1,700 feet above sea level is attained, consists not of sharp knobs but of a massive accumulation covering several square miles and rising like a great dome above the surrounding moraine. The greater part of it has already been brought under cultivation while neighboring lower districts with more broken surface still remain uncultivated. In Barry County, especially southwest of Hastings, the Kalamazoo morainic system is characterized by larger lakes than are commonly found elsewhere along the interlobate tract. Indeed, lakes are not so conspicuous in this interlobate tract as in the one between the Saginaw and Huron-Erie lobes. Small lakes and marshy depressions are, however, very common all through it.

The interlobate tract includes several small gravel plains which were developed as outwash from one or both of the ice lobes. They are in places thickly set with basins—conspicuously so as a rule at the border between the gravel plains and the associated moraines. The distribution

of the basins and the slope of the plains indicate the source of the outwash, which in some places appears to have been the product of but one of the lobes. For instance, a plain north of Grand Rapids on the east side of Grand River has conspicuous basins on its eastern edge next to the moraine of the Saginaw lobe, and it slopes from that moraine toward Grand River. The northeastern portion of a plain in northwestern Montcalm County and neighboring parts of Mecosta and Newaygo counties rises toward the moraine of the Saginaw lobe, but a narrow southern extension rises toward the west to a moraine of the Lake Michigan lobe. The plain in northeastern Allegan County and the large plain outside the Kalamazoo morainic system in southern Barry and neighboring parts of Kalamazoo counties both seem to have been joint products of the Saginaw and Lake Michigan lobes, for they slope away from a moraine of each lobe.

On the whole, gravel plains are rather poorly developed in this interlobate tract. The most conspicuous is one that covers perhaps 100 square miles in northwestern Montcalm and neighboring portions of Mecosta and Newaygo counties. Another in eastern Allegan County is of similar size if the entire outwash from the Lake Michigan lobe in the district north of Kalamazoo River is included. The gravel plains in the vicinity of Grand Rapids and northward from there into northern Kent County are all very small, amounting altogether to scarcely 100 square miles.

In the very massive part of the interlobate moraine from southern Mecosta County northward to Cadillac, the only gravel plains are along the valleys of the principal streams, Muskegon and Hersey rivers. The one on the Muskegon is largely a line of glacial drainage from the headwaters of Muskegon River and is therefore to but slight extent referable to drainage attending the development of the interlobate tract. The plain along Hersey River appears to be an outwash from the Lake Michigan side of the interlobate moraine. This massive part of the moraine is made up of strips of gravelly or sandy moraine alternating with strips of somewhat clayey moraine. These gravelly and sandy strips are thought to correspond in a certain degree to outwash aprons, but owing to the nearly complete coalescence of the ice lobes the gravel and sand was prevented from being spread out in a plain and has a topography similar to the remainder of the moraine.

The relation and trend of the morainic ridges of the Saginaw and Lake Michigan lobes in the interlobate district indicate the northward shift of the reentrant angle. The moraines of the Saginaw lobe lead up to the line of junction from the southeast, and those of the Lake Michigan lobe lead up to it from the southwest or south, and the outwash aprons or gravel plains just mentioned occur at the junction. The reentrant appears to have worked back northward to the southwestern part of Mecosta County while the massive moraine which extends northward from there to Cadillac was yet in process of formation. From this massive moraine the lobes probably shrunk away, the Saginaw to the east and the Lake Michigan to the west, uncovering it simultaneously along nearly the entire length, instead of retreating along it from south to north.

STRUCTURE OF THE DRIFT.

THICKNESS.

The rock surface beneath this interlobate tract probably in no place greatly exceeds 700 feet above sea level and may in places drop to as low as 200 feet above the sea. The drift surface ranges from 700 to 1,700 feet. The thickness of the drift may, therefore, in places exceed 1,000 feet and it probably averages more than 500 feet. Yet there is a small area in the vicinity of Grand Rapids where the rock is near the surface and where all but one of the borings that have reached rock are located. The one exception is the Red Cross mineral well near Big Rapids, which penetrated about 450 feet of drift and struck rock at 525 feet above sea level. A boring made by the Grand Rapids & Indiana Railway at Big Rapids reached a depth of 245 feet (670 feet above sea level) without striking rock. A waterworks boring at Big Rapids 200 feet in depth terminated at an altitude 680 feet above sea level without striking rock. At Reed City a boring at the waterworks and another at the electric-light plant, each about 275 feet in depth, terminated at 750 feet above sea level without reaching rock. A well only a

mile from the highest point in the southern peninsula, on the farm of Albert Miller, sec. 11, T. 20 N., R. 9 W., at an altitude of 1,580 feet, was sunk 337 feet without striking rock.

No means have as yet been found for determining how much of this great mass of drift is referable to the Wisconsin and how much to preceding stages of glaciation. The convergence of the ice lobes and the comparatively small removal by glacial drainage favored a large accumulation of drift, and the amount deposited at the last ice invasion may be as great as the relief of the ridges, or an average of about 300 feet.

COMPOSITION.

The surface portion of the drift, particularly in the northern part of the morainic tract, presents interesting alternations of gravelly or sandy drift with a somewhat clayey drift. In the southern part the sharp ridges and knolls are largely of gravel and sand and the gently undulating tracts are chiefly of till. Till is in some places only a thin veneer over thick deposits of gravel and sand; this is especially noticeable in the district southwest of Hastings, where wells have been sunk to 150 to 200 feet entirely through sand and gravel except 10 to 20 feet of clayey material at the surface. The variations in structure can perhaps be best described from south to north, in the direction of ice retreat and the order of development of the morainic tract.

In Barry County, southwest of Hastings in the vicinity of the junction of the outer moraine of the Kalamazoo system and its correlative of the Saginaw lobe, the moraine is chiefly of sand and gravel with a thin veneer of bowldery till. In places, especially east of Gun Lake and south of the bend of Thornapple River below Hastings, the surface is sandy. From Hastings directly northwestward to Grand Rapids the drift appears to be entirely from the Saginaw lobe and is chiefly clayey till. Some surface sand appears along the borders of Thornapple River. In the bend of the river north of Grand Rapids sand and gravel lie along the immediate edge of the valley, but a stiff clayey till is found farther back. The moraine on the north side of Grand River west of Grand Rapids was produced by the Lake Michigan lobe and is also largely of till with more or less sand near the edge of the Grand and Rouge river valleys. In the northern part of Kent County, from the Grand Rapids & Indiana Railway west to Rouge River and also for 2 to 4 miles east of the railroad, the drift is largely gravelly and sandy, but farther east it is prevailingly clayey till.

Considerable clayey till occurs in the part of Montcalm County south of Tamarack Creek in a district covered by the Saginaw lobe. Gravelly drift appears, however, over an area of perhaps 50 square miles on the west side of Flat River in northern Montcalm County, much of which is sharply ridged. The smoother tracts to the north are about equally divided between clayey and sandy drift.

A prominent ridge formed by the Lake Michigan lobe in the southeast part of Newaygo County has clayey till on its western slope but is gravelly and sandy on its crest and eastern slope. The morainic system in eastern Newaygo County north of Muskegon River is very largely of sandy and gravelly drift, but is of clayey drift over about 10 square miles in the northeast corner of the county in the eastern part of Barton Township. This clayey drift extends eastward to the Muskegon Valley in Mecosta County north of Big Rapids, and northward in a strip several miles wide along the line of Lake and Osceola counties to the vicinity of Leroy in western Osceola County. West of it in Lake and Newaygo counties there is an elevated range of gravelly and sandy hills.

In Mecosta County the district between the Muskegon and Little Muskegon valleys carries a succession of clayey and sandy strips trending nearly east to west. In the southwestern part of the county a clay strip about 5 miles wide running westward from Altona past Borland lies immediately back of the large outwash apron developed by the Saginaw lobe and is apparently the product of the Saginaw lobe. North of this clayey tract, in the northern half of Austin Township and south of the line from Byers to Rodney, a very sandy morainic tract 4 to 6 miles wide stands higher than the till tracts on either side. Immediately southeast of Big Rapids a till tract has its northern border near the line of the Pere Marquette Railroad between

Big Rapids and Rodney. North of this is another sandy tract that has its northeastern limits near Chippewa Lake and its southeastern limits near Rodney; it is less elevated than the sandy tract in Austin Township and in places has the general features of a pitted gravel plain, These sandy tracts have very few surface bowlders compared with the number on the bordering till tracts. A large section of the moraine lying along a line running from Big Rapids past the north end of Chippewa Lake to Barryton and extending on the north to Muskegon River has a preponderance of till but includes small areas of sandy and gravelly drift.

North of Muskegon River, in central Osceola County, an area of about 75 to 100 square miles of very sandy and elevated moraine is entirely surrounded by lower tracts with a somewhat clayey drift. In the northern part of Osceola County, on the highest land of the southern peninsula, considerable till is present, the sandiest tracts being in the relatively low districts in the northwestern and northeastern parts of the county.

Along the southern edge of the southeastern township of Wexford County and in much of the southwestern township of Missaukee County clayey drift is present, but in the district immediately east of Cadillac at the extreme northern point of the interlobate moraine an area of several square miles is very sandy.

BOWLDERS.

Bowlders, which are almost or wholly lacking on other sandy portions of the moraine, thickly strew the sandy district in central Osceola County. They are less numerous on the sandy strip in eastern Lake and eastern Newaygo counties than they are on the clayey tracts to the east, but they are by no means rare in either place. Except on the small sandy areas they average several thousand to the square mile on the prominent part of the morainic system from Cadillac southward to southern Mecosta County. In the southern part they are generally concentrated in the vicinity of the sharper ridges and knolls and are relatively scarce on the gently undulating tracts, being most prevalent in western Barry County and especially in the district southwest of Hastings, where they are almost as numerous as in the prominent northern portion.

GLACIAL DRAINAGE.

The drainage from the reentrant between the Lake Michigan and Saginaw lobes at the junction of the outer moraine of the Kalamazoo system and its correlative moraine in the Saginaw lobe was southward from southern Barry County across central Kalamazoo County to St. Joseph River below Centerville. It passed directly across the present course of Kalamazoo River east of Kalamazoo. Its gravel plain has an altitude of nearly 1,000 feet at its head near Prairieville in Barry County, but descends to less than 900 feet at the bluff of Kalamazoo River, to about 800 feet at the place where it enters Indiana a few miles southwest of Centerville, and to about 720 feet at the bend of St. Joseph River near South Bend, Ind. From South Bend the discharge was down the Kankakee to the Illinois and thence to the Mississippi and the Gulf of Mexico.

From the reentrant between the two ice lobes in northeastern Allegan County the drainage was southward along the Gun River valley to the Kalamazoo and thence either to South Bend through the low tract west of the Kalamazoo morainic system or down the Paw Paw Valley to a glacial lake held in front of the ice near the mouths of Paw Paw and St. Joseph rivers. It is probable that the former course was in operation until after the ice had withdrawn from this gravel plain, and that the latter course was utilized by the later glacial drainage that came down the Thornapple Valley.

From the reentrant between the two ice lobes at the bend of Grand River north of Grand Rapids the drainage was southward along a well-defined valley that led past Ross and on through northern Allegan County. It appears to have continued for a time southward to the Kalamazoo Valley at Allegan, but on the withdrawal of the Lake Michigan ice lobe from a moraine north of Allegan it shifted to the west side of the moraine and made its way southward along the edge of the receding ice to the head of Lake Michigan and thence to Desplaines, Illinois, and Mississippi rivers.

From the reentrant angle a few miles south of Big Rapids the drainage appears to have passed southward from the Muskegon Valley to the head of the Rouge River valley and thence to Grand River, beyond which it probably followed the course past Ross previously outlined. As the ice lobes separated this line of glacial drainage extended up the Muskegon Valley as far probably as the vicinity of Hersey. There appears also to have been some drainage from the Lake Michigan lobe down Hersey River to Hersey. The portion of the Muskegon above Hersey served as a line of glacial drainage until the ice sheet had receded east of the headwaters of the river, or until later than the development of the morainic system under discussion.

KALAMAZOO MORAINIC SYSTEM OF THE SAGINAW LOBE.

COURSE AND DISTRIBUTION.

The Kalamazoo morainic system of the Saginaw lobe connects at the west with the Kalamazoo morainic system of the Lake Michigan lobe and appears to be its full correlative. Its outer or southern border is definitely limited by a large outwash apron along much of its course, the only exception being a few miles in western Jackson County, where it terminates in a hilly district through which lines of border drainage were developed. The border trends southeastward from Prairieville in southwestern Barry County across the northern part of Calhoun County into western Jackson County. Near the village of Spring Arbor, about 10 miles west of Jackson, it swings to north of east and runs past Jackson to the edge of Washtenaw County, where it connects with the correlative system (Mississinawa morainic system) of the Huron-Erie lobe. The belt is only about 2 miles wide east of Jackson and for a few miles in the vicinity of Marshall, but elsewhere is 6 to 12 miles wide. At its western end it occupies the entire space between Prairieville and Hastings, its north border in the vicinity of Hastings being Thornapple River valley. It is also of great breadth along the east side of Battle Creek, where a spur extends from it northward nearly to Charlotte. In northwestern Jackson County it is separable into three more or less distinct moraines with intervening narrow strips of gravel plain and border drainage. The inner members of the system, however, die out or become very diffuse east of Grand River.

TOPOGRAPHY.

ALTITUDE.

The relief of this morainic belt above the gravel plain on its outer border is but slight, in most places being less than 30 feet and in few more than 50 feet. The gravel plain, however, is elevated, the altitude in the reentrant angle between the Lake Michigan and Saginaw lobes being nearly 1,000 feet and in that between the Saginaw and Huron-Erie lobes more than 1,000 feet above sea level. The border drainage lines leading westward from Jackson are also between 950 and 1,000 feet above sea level. The lowest part of the border is in the vicinity of Battle Creek, where the gravel plain is scarcely 900 feet and the moraine only about 950 feet. The moraine is traversed by several streams, such as Wabascon, Wanandager, and Battle creeks, but these streams run in deep depressions whose borders are higher than the plains in which the streams have their sources.

RELIEF.

The inner border relief is inconspicuous in Eaton and Barry counties, there being in places a gradual transition from the moraine to the bordering till plains. In northeastern Calhoun County a large swamp lies immediately north of the moraine, but its altitude is only 25 to 50 feet below the bordering morainic ridges. The moraine leading northeastward from Jackson rises nearly 150 feet above the Portage swamp which lies on its north border, this being the most prominent part of the entire morainic system. The relief of the ridges in northwestern Jackson County above the depressions occupied by Grand River and Sandstone Creek in places exceeds 100 feet.

CHARACTER.

In western Barry County, where this morainic belt connects with the Kalamazoo system, knob and basin topography prevails, sharp knobs rising 50 to 100 feet above the surface of the numerous lakes inclosed in basins. Southeastward the lakes become more scattered, but knob and basin topography continues along much of the moraine. Not a few of the knobs rise abruptly 50 to 60 feet, but these are interspersed with many low knolls 20 feet or less in height. In the vicinity of the Battle Creek valley marshy tracts of considerable extent are inclosed by sharp sandy knolls, some of which are 60 feet or more in height. Wanandager Creek crosses the moraine through a swampy plain. Knolls 60 feet or more in height are numerous along the east side of Battle Creek as far north as Olivet. In eastern Calhoun and western Jackson counties a few knolls are 50 or 60 feet high, but the great majority reach only 15 or 20 feet. Swampy east-west valleys that traverse the district are thought to have carried the border drainage to Kalamazoo River. Some of them are occupied by Rice Creek and its tributaries, but others are not traversed by streams at the present day. Narrow strips of nearly plane gravelly land alternate with the morainic strips. Many of the plains are pitted and appear to be outwash aprons formed on the front of the receding ice border. Near the mouth of Sandstone Creek, in northwestern Jackson County, knolls fronting on the Grand River valley rise abruptly 80 to 100 feet above the valley bottom, but farther south the moraine is smoother. To the east, in Rives Township, knolls 40 to 60 feet in height rise abruptly from swampy tracts, and an esker leads southward from Rives Junction nearly to the city of Jackson.

The sharp morainic belt leading from Jackson eastward along the south side of Portage Swamp contains knobs 75 to 100 feet or more in height which stand near the south border of the range. An undulating strip a mile or more in width extends from the base of these knobs down to the border of the swamp.

North of the Portage Swamp knolls are found only in clusters or small detached areas surrounded by nearly plane tracts of sandy drift which rise northward into a later morainic system, the Charlotte. These are probably correlatives of better-defined morainic belts in northwestern Jackson County.

STRUCTURE OF THE DRIFT.

COMPOSITION.

On the whole, the drift of this morainic system is of rather sandy texture. It tends to grade into clayey till toward the inner or north border, especially in Barry and Eaton counties. In Calhoun and Jackson counties, where the underlying rock is sandstone, the till is generally sandy.

BOWLDERS.

Bowlders are found in great numbers along much of the southern edge of the moraine from Barry County to Washtenaw County. They are least conspicuous in the vicinity of the Battle Creek valley, where the drift is exceptionally sandy. Bowlders are also found some distance back from the border in belts, many of which are traceable for several miles. In central and western Jackson County, as in districts to the south where sandstone hills are present, small surface bowlders are remarkably numerous—so numerous, indeed, that fences miles in length are built of them. Many of them are only a foot or two in diameter. The great majority are of granitic rock and are rounded by exfoliation. The bowlders appear to be much more numerous on the surface than beneath it; their numbers are rarely troublesome in well borings even where the surface is thickly strewn.

In the vicinity of the reentrant angle in Barry County bowlder belts trend north-northeast and south-southwest, the direction corresponding pretty closely to that of the ridges of the Lake Michigan part of the Kalamazoo system. East of this reentrant angle, however, the bowlder belts trend north-northwest and east-southeast, conforming to the direction of the Saginaw part of the Kalamazoo system.

THICKNESS.

In the vicinity of the reentrant angle in Barry County, between the outer moraine of the Kalamazoo system and its correlative in the Saginaw lobe, records were obtained of several wells 80 to 150 feet in depth, all of which terminate in drift. The bowldery surface clay is commonly but 5 to 10 feet thick and is underlain to a considerable depth by sand. East of the reentrant angle the lower parts of wells contain till, alternating with thin beds of sand and gravel. There are, however, considerable areas in which very little till occurs except in the thin sheet at the surface. Many wells reach depths of 80 to 90 feet. Some penetrate a blue quicksand, generally beneath blue till, but in most of them the sand is gray or yellowish and is moderately coarse.

In Calhoun County west of Battle Creek records of wells 100 to 125 feet deep show a large amount of assorted material, some of which is described as reddish sand and some as gravel and sand. In sec. 16, Penfield Township, two wells, 110 and 125 feet deep, stand on a very prominent portion of the moraine 80 to 100 feet above the valley of Battle Creek. The 110-foot well has the following record:

Record of well in Penfield Township, Calhoun County, Mich.

	Feet.
Bowlder clay, yellow	15
Bowlder clay, blue-gray	4
Cobble, gravel, and sand	50
Sand, reddish	35
Gravel and water	6
	110

In much of Convis Township, which lies east of Battle Creek valley, the drift is very sandy, but in the southwestern portion the soil is heavier and the wells encounter considerable bowlder clay, though even here some wells are largely in gravel and sand. In the vicinity of the swamp in Lee Township wells are reported to penetrate a slightly pebbly blue-gray clay. In northern Marengo Township wells penetrate yellowish till for 8 to 15 feet and then commonly enter dry sand, though some find bluish till. In the northeastern townships of Calhoun County the wells indicate that the drift is mainly sand and gravel; some of the wells pass into rock at depths of 50 feet or less.

The spur which runs northward into Eaton County along the east side of Battle Creek contains considerable clayey till, but carries gravel knolls and a short esker. Some of the wells are in sand or gravel in their lower and clayey till in their upper part. Native copper is reported from the drift about Olivet. Knolls in the village of Olivet are gravelly, but some of them are shown by wells to contain a blue till at about the level of their base.

In northwestern Jackson County sandstone is entered in most wells at depths of less than 50 feet though in some the drift goes down about 100 feet. It is commonly sandy or loose textured throughout but is not definitely assorted, the sand being derived from the local sandstone.

The strong moraine leading eastward from Jackson is gravelly and so far as ascertained contains but little clayey material. Many of its knolls show abrupt changes from sand to gravel and cobble. North of the Portage marsh sand in places forms but a thin cover over the till; wells are obtained at slight depth (some after penetrating only 5 or 6 feet of till), and the extent and depth of the till is not known.

INNER BORDER.

GENERAL CHARACTER.

Only narrow strips of plain lie between the Kalamazoo and Charlotte morainic systems and between the constituent ridges of the Kalamazoo system. The strip between Marshall and Charlotte is the widest, attaining a width of 15 miles; the ordinary width is less than 10 miles. The strip between the outer and second ridges in Jackson County is nearly 6 miles wide where widest. Along Portage River it is largely a sandy swamp, but west of Grand River it is a cultivable till plain, traversed by a sharp esker ridge. A small area of cultivable sandy till lies north of

Portage River near its mouth. In western Jackson and eastern Calhoun counties the narrow strips between the ridges of the Kalamazoo morainic system are sandy or gravelly and in part swampy.

The strip between the Kalamazoo and Charlotte morainic systems in Barry and Eaton counties is gently undulating till of high fertility. In Calhoun County it is largely swampy, including a swamp covering much of Lee Township. In southern Ingham County it includes sand plains, large marshes, undulating till tracts, and a few sharp gravel ridges of esker type. In places it so grades into the bordering moraine as to be difficult to delimit.

The drift is of moderate thickness, 30 to 60 feet or less (aside from preglacial valleys), in much of the district east of Battle Creek. West of that stream it is much thicker because of the lower altitude of the rock surface, and in eastern Barry County it probably exceeds 150 feet.

One occurrence of buried soil between drift sheets is known. A well on the farm of Mr. Diebolt in the southwest part of sec. 25, T. 2 N., R. 6 W., in western Eaton County, penetrated a black muck under till at 35 to 40 feet from the surface. Below the muck was a sand that yielded water. Neighboring wells go down 75 to 100 feet and in one place 190 feet without reaching rock, so it is probable that this black muck is between the Wisconsin and Illinoian till sheets.

The most striking features of the tracts between the two morainic systems are the eskers which occur both as long chains of gravel ridges and as isolated short ridges.

RIVES ESKER CHAIN.

The Rives chain of ridges is one of several that extend from the low plains near Lansing up through the strong moraines to the south. Several of the eskers do not reach to the Kalamazoo morainic system but terminate in the next later or Charlotte system. The Rives esker system sets in at the south border of the Charlotte system and leads southward in disjointed sections for about 16 miles, nearly to Jackson. Its southern portion, from Rives Junction southward, was probably formed while the ice border was still holding its position at the moraine in Jackson. Another section, which lies entirely north of Grand River, is likely to have been formed after the ice border had shrunk back nearly to the line of Ingham and Jackson counties. The third or northern section, which lies in the outer edge of the Charlotte morainic system, may prove to be as young as that morainic system. The fact that these esker ridges lie end to end in a nearly continuous esker trough is taken to indicate that they have at least been formed in close succession by an essentially continuous subglacial stream. It may seem remarkable that a subglacial stream should have maintained its track during so great a recession of the ice border, but this is only one of several esker systems in southeastern Michigan which seem to require this interpretation.

The southern section leads a little east of south from Rives Junction, nearly to Jackson, a distance of about 7 miles. It lies in a swampy depression, one-eighth to one-fourth mile in width, which is utilized by the Michigan Central Railroad and the Jackson-Lansing Electric Line. The greater part of the esker is in view from the railway trains. Except for a mile or so at the north end, which is strongly morainic, the district bordering the esker is a gently undulating till plain, in which the esker terminates at the south without any gravel fan or delta. However, a number of kames within a mile south of it in the northwestern part of Jackson may perhaps be the product of the same stream which produced the esker. The height of the esker ranges from 5 feet up to nearly 50 feet. Its highest part was in the village of Rives Junction, but this has been removed for railway ballast. The esker seems to contain a large amount of gravel suitable for railway ballast, but pits on its eastern slope near Rives Junction contain also beds of sand.

The middle section has its southern terminus directly across the valley of Grand River about 1½ miles northwest of Rives Junction and its northern end about 4 miles to the north in sec. 24, Onondaga Township, Ingham County. It lies in secs. 24 and 25 and the north part of sec. 36, in a swampy depression which extends a mile or more farther north than its north end. From the southeast part of sec. 36 southward to Grand River the esker lies on the slope

of a small north tributary of Grand River and is less continuous than in the swampy channel to the north. Much of it is only 10 or 15 feet high, but in the middle part of its course it attains a height of about 40 feet. At the southern end it divides into a network of ridges which incloses basins. Opposite its south end, on the south side of Grand River, a gravelly plain containing basins and standing 15 to 30 feet above the stream may prove to be a delta or fan connected with it.

The third or northern section is in a swampy depression in the headwaters of Willow Creek in the northeast part of Onondaga Township. The swamp extends from the north line of the township southward along the border of secs. 1 and 2, 11, and 12, into sec. 13. It is separated from the swampy channel containing the middle section of the esker by an undulating tract of sandy drift about half a mile wide. The esker is a low ridge, commonly but 15 to 20 feet high, which winds back and forth across the line of secs. 11 and 12 in a general southward course. A short parallel esker ridge lies in the southeast part of sec. 11. Near the southern ends of these ridges lies a group of sharp kames 40 or 50 feet high and beyond these the gently undulating tract just mentioned. The trough in which this esker lies is in the outer part of the Charlotte morainic system and is bordered by a very bowldery, knob and basin morainic tract. The middle section of the esker, on the other hand, has its entire course through a gently undulating tract such as separates the moraines of this region.

The excavations in the Rives esker throughout its entire length show a large preponderance of material of local derivation, Carboniferous sandstone being conspicuous and forming a great majority of the cobbles and coarser stones. This is interesting in view of the fact that the surface bowlders of the border districts are very largely granitic rocks of distant derivation. The stream which formed the esker appears therefore to have derived its material from very near the base of the ice sheet. A similar condition has been noted in many other eskers in Michigan and neighboring States.

The swampy depression along the line of the esker was probably not excavated in a single tunnel, for in many places it is one-fourth mile or more in width. It is more probable that the subglacial stream shifted back and forth, carrying away the englacial material which would otherwise have gone to fill this depression. The depressions or esker troughs antedate the esker ridges, the ridges being the last feature produced before the disappearance of the ice.

The kames associated with parts of the esker seem likely to have been closely connected with it in origin and to have been developed by the concentration of material in openings in the ice. The material in the kames, like that in the eskers, is largely local, indicating that it came from the basal portion of the ice sheet.

WALTON ESKER CHAIN.

The Walton esker chain lies in Walton Township, Eaton County, a few miles southwest of Charlotte, along the borders of the Battle Creek valley. Its northern end is in secs. 2 and 3, Walton Township, just south of a swamp which bears westward from Battle Creek toward Olivet station and which seems to have been a line of glacial drainage that comes back to the Battle Creek valley south of the station. The present valley of the creek is very narrow and seems hardly adequate to have carried the glacial drainage.

A complex network of ridges 5 to 15 feet high, among which are basins and level gravelly tracts, forms the head or northern end of the esker in secs. 2, 3, 10, and 11. The ridges lead into sec. 15, to what seems to be an esker delta or fan-shaped plain that stands about 40 feet above the creek, the whole constituting the northern and probably the youngest section of the esker chain. The delta plain lies south of the Battle Creek valley and extends nearly a mile west from the intersection of Big and Battle creeks; it contains basins 20 feet deep but otherwise is nearly level.

The second section of the chain consists of a sharp gravel ridge 30 to 40 feet high which leads south from the southwest part of sec. 15 and which is bordered on each side by narrow swampy depressions. This leads into a fan-shaped expansion, with nearly level surface, which

lies about 2 miles south, in the east part of sec. 27, and which constitutes the southern end of the section. The ridge has been opened for gravel in a few places and also for building sand, for it is found to be sandy in places. The bedding, though usually horizontal, is in places sharply inclined toward the south.

The next section begins in the south part of sec. 27, whence a sharp ridge curves across the northwest part of sec. 34 and ends in another fan. This seems to be the end of the chain, though sandy and gravelly knolls west from its northern part in secs. 21 and 27, in a strong moraine near Olivet village, may have been developed in connection with it.

A capping of brown clayey and sandy gravel, 2 to 4 feet thick, covers the uneven and eroded surfaces of beds of assorted material. Beds that contain but little sand are nearly horizontal, but beds with much sand dip quite perceptibly toward the west, some of them 30° or more. Scarcely any of the pebbles exceed 2 inches in diameter, and the great bulk of them are one-half inch or less. Of 221 pebbles having a diameter one-fourth inch or less, 136 were sandstone, limestone, and chert of local derivation; the remaining 85 were Archean, principally granites. Of 52 fine pebbles having a diameter of one-fourth to one-half inch 30 were sandstone and limestone of local derivation and 22 were Archean rocks, principally granites. Coarser pebbles are principally sandstone but no count of them was made. No striated pebbles were observed, but this is perhaps due to abrasion in the glacial stream.

This chain of eskers shows more clearly than is usual in eskers evidence of consecutive northward extensions due to recession of the ice border. The tunnels in which the eskers were formed apparently had a length of only 2 or 3 miles at the most. The apparent exclusion of glacial drainage from the part of the Battle Creek valley in which the esker chain occurs is difficult to explain unless stagnant ice masses persisted along this depression during the time of the glacial drainage through the swamp leading past Olivet station. This drainage is discussed in connection with the Charlotte morainic system.

SMALL ESKERS.

Besides the esker chains above described minor ones are scattered through the moraine in various situations. They consist of single ridges a fraction of a mile in length that are either isolated or are very remotely connected with other eskers. One was noticed in the Grand River Valley about 2 miles north of Onondaga. Several small eskers occur in the valleys of the north tributaries of Portage River in northern Jackson and southern Ingham counties.

OUTWASH.

DISTRIBUTION AND CHARACTER.

The outwash plains on the border of the Kalamazoo morainic system of the Saginaw lobe are among the most conspicuous in Michigan. They are extensive in the reentrant angles between the Lake Michigan and Saginaw lobes and the Saginaw and Huron-Erie lobes, and also along the front of the Saginaw lobe from the meridian of Kalamazoo eastward to the meridian of Marshall, and from Jackson eastward to the Huron-Erie reentrant. Between Jackson and Marshall there are channels formed by the glacial drainage along or near the ice border. The entire system of outwash aprons and channels found discharge southward along the eastern edge of the Lake Michigan lobe to the St. Joseph Valley near Three Rivers, and thence past South Bend to the Kankakee, from which, as now, the drainage led to Illinois and Mississippi rivers and the Gulf of Mexico.

The outwash aprons are throughout indented by numerous basins, some 2 or 3 square miles or more in extent, but the majority only a fraction of a square mile. Many of them are 20 to 30 and some 50 to 60 feet deep. As a whole they occupy nearly as much area as the flat parts of the outwash. On their slopes and beds some bowlders and many sharp hummocks are found. To the eye the basins appear to be morainic, but they are probably due to the presence of masses of stagnant ice during the building up of the outwash plains around them.

On the outwash plains surface bowlders are rare, and the plains rise above the level of the knolls that stand in the basins.

The outwash is very largely fine gravel, though in places on the immediate border of the moraine it carries cobbles and even coarser rock material at the surface. It commonly includes sand and in places is so sandy as to be unsuitable for road ballast. The large amount of the sand is probably attributable to the interruptions to free flow by masses of stagnant ice and also to the wide branching and rather low gradient of the streams flowing away from the ice sheet.

The plain in the reentrant between the Saginaw and Huron-Erie lobes slopes gradually southwestward toward the valley of Wolf Creek, an eastern tributary of Grand River entering at Jackson. It has a width near Grass Lake of about 6 miles. Its altitude at the border of the moraine north and northeast of Grass Lake is about 1,030 feet, but between Grass Lake and Wolf Creek it scarcely exceeds 1,000 feet.

BORDER DRAINAGE.

The border drainage led westward from Jackson at different levels; the altitudes of the outer or southern channels, which pass south of Spring Arbor, are between 990 and 1,000 feet, and those of the northern ones, which lead past Trumbull station west of Jackson, are about 960 feet on the divide between Sandstone Creek, a tributary of Grand River, and Rice Creek, a tributary of Kalamazoo River. The altitude of a channel east of Parma leading more directly to the Kalamazoo Valley is also about 960 feet. The width of these channels is irregular, being commonly one-fourth mile, but ranging up to nearly a mile. They generally have steep banks or low bluffs 15 to 20 feet in height. Their bottoms are marshy, for their gradients are too low for the present small streams to drain them effectually. Portions of the beds in the vicinity of Parma are thickly strewn with bowlders, so that the land if drained could scarcely be cultivated. It is probable that the northern channels formed the outlet for the outwash tract in the reentrant east of Jackson during much of the time it was receiving outwash from the bordering ice lobes.

The westward descent brings the channels along Rice Creek and Kalamazoo River down to about 900 feet, at which level they open into the gravel plain near Marshall. The altitude of the gravel plain next to the moraine is more than 900 feet for several miles west of Marshall and over a considerable area in the reentrant between the Saginaw and Lake Michigan lobes in northeastern Kalamazoo and southwestern Barry counties, but in the vicinity of Kalamazoo River it is a little less than 900 feet. It seems to have been about 875 feet where the drainage turned southward from the Kalamazoo toward the St. Joseph Valley in eastern Kalamazoo County.

THICKNESS.

The thickness of the outwash deposit is known only in places where wells pass from the surface gravel into underlying till or into bedrock. A few wells northeast of Kalamazoo on an elevated part of the gravel plain enter till at about 40 feet. Directly east of Kalamazoo on the south side of Kalamazoo River the outwash deposit is very thin, so that the till in places is at the surface. This tract, however, has suffered some erosion because of the concentration of so much glacial drainage. In the district between Battle Creek and Marshall the outwash gravel seems to have been but a few feet thick, for the ravines cut down into bowldery drift and in places sandstone is near the surface. The depth of the outwash material in the plain east of Jackson is likely to equal the depth of the basins, which is 30 to 50 feet.

INTERLOCKING MORAINES OF THE SAGINAW AND HURON-ERIE LOBES IN SOUTHEASTERN MICHIGAN.

The "thumb" or southeastern watershed of Michigan, the high divide draining on the east into Lake St. Clair, Detroit River, and Lake Erie and on the west into Lake Michigan and Saginaw Bay, has a rock nucleus but is also occupied by a prominent system of interlocking moraines formed between the Saginaw and Huron-Erie lobes. Moraines of Wisconsin age are to some extent superimposed upon moraines of an earlier (Illinoian) stage of glaciation, for the lobation of the ice in the earlier stage naturally was governed by topography in a manner similar to that in the later stage.

Many years ago, in the Douglass Houghton reports of the first Michigan Survey, the leading topographic features of the divide were so described as to lead one familiar with modern interpretation to infer that it consisted of strong moraines. Years later the system of moraines was recognized and its general features were discussed by Chamberlin,[1] who termed it an interlobate moraine of the Saginaw and Western Erie lobes and who demonstrated its relation to the lobes of the great Labrador ice sheet. It was not, however, until detailed studies were made by the present writer that the presence of moraines and drift ridges of pre-Wisconsin age was noted, or that it was determined that the drift, instead of being a single massive moraine traversing the entire length of the district between the Saginaw and Huron-Erie ice lobes, consists of several interlocking moraines leading up from either side at such angles as to form a reentrant in which the drift is heaped up. This heaping up, repeated in the several moraines which interlock in succession from southwest to northeast, constitutes what is here termed the interlobate morainic belt.

The moraines of the interlocking system in northern Indiana and southern Michigan have already been discussed in connection with the development of earlier moraines of the Saginaw lobe. The present discussion, therefore, begins in southern Jackson County, Mich., where the outer moraine of the Kalamazoo system of the Saginaw lobe connects with the correlative moraine of the Mississinawa system of the Huron-Erie lobe, and extends northeast to southern Lapeer County, north of which no entanglements are found. The entire length of the system in Michigan is 150 miles and its width 25 miles.

DISTRIBUTION AND CHARACTER.

At the place of interlocking flat outwash aprons and lines of glacial drainage strikingly contrast with the sharp knobs of the moraines with which they are connected. When the southwestern end of the interlocking system was forming the reentrant in the ice border appears to have been slight, but with the development of the system it became more marked. As in northeastern Indiana, the Saginaw lobe receded more rapidly than the Huron-Erie lobe, but the reentrant between the lobes receded still more rapidly than the end of the Saginaw lobe, and the Saginaw lobe consequently is more clearly defined in the later than in the earlier moraines of the interlocking system.

The Kalamazoo system of the Saginaw lobe connects with its correlative of the Huron-Erie lobe in southern Jackson County in the vicinity of Hanover, which stands on a small gravel plain in the reentrant between the two ice lobes. North of the village is a moraine of the Saginaw lobe and south and east of it a moraine of the Huron-Erie lobe. The morainic spur developed at the junction is more prominent than either moraine and extends northeastward to a point about 6 miles south of Jackson where it terminates in a kame that stands 200 feet above Grand River, which flows at its northern base. The spur carries numerous knolls 50 to 75 feet high in groups or in short belts between which are lower tracts with small knolls.

At the northeast end of this prominent morainic spur a gently undulating till tract covering an area of about 30 square miles extends from the southern line of Jackson County northward within 3 or 4 miles of the city of Jackson and eastward about to Brooklyn and Napoleon.

[1] Chamberlin, T. C., Preliminary paper on the terminal moraine of the second glacial epoch: Third Ann. Rept. U. S. Geol. Survey, 1883, p. 328.

It is traversed nearly centrally by a sharp gravelly ridge, 30 or 40 feet high and about 7 miles long, which leads from the south side of Wolf Lake southwestward to the middle of the morainic spur. This ridge is a little broader than a typical esker, being in places nearly one-eighth mile in width, but it appears to have been developed by the same process and to be referable to the esker class. Like the morainic spur it seems to lie very nearly along the line of junction between the Saginaw and the Huron-Erie lobes.

From the till plain just described northward past the Michigan Central Railroad and eastward about to the line of Jackson and Washtenaw counties there is a gravel plain, known as the Grass Lake Plain, which rises on the north into a prominent moraine of the Saginaw lobe and on the east into a prominent moraine of the Huron-Erie lobe. It carries numerous basins and connecting sloughs so that only a small part of its surface is up to the level of the plane of deposition. At its northeastern end it extends as a narrow strip scarcely a mile wide for 2 or 3 miles into the midst of the coalesced morainic belt and has its head a mile north of Kavanaugh Lake at the base of Sugarloaf Knob in sec. 32, Lyndon Township, Washtenaw County.

The moraines which border the Grass Lake Plain form a prominent spur about 5 miles wide, from their point of union in northwestern Washtenaw County northeastward about to Pinckney, in southern Livingston County, a distance of perhaps 10 miles. Part of it is within the limits of the Ann Arbor quadrangle. The area of the spur is called by the residents the "short-hill district," because its thickly set knobs give short but sharp gradients to the roads which traverse it and have very little level surface. It is also thickly set with basins, the largest of which are nearly a mile in longest diameter and one-fourth to one-half mile in width. A number of them contain lakes, some of which are reported to have depths of 75 feet or more, with water surfaces fully 100 feet below the highest neighboring parts of the moraine. The land surface outside the lakes in this morainic spur has a range of about 200 feet in altitude, or from 900 to 1,100 feet above sea level.

From the northeast end of the interlobate spur eastward across southern Livingston County clusters of sharp kames and interspersed gravel plains (see Howell and Ann Arbor topographic sheets) converge toward a gravel plain which leaves Huron River near Portage Lake and leads westward as a prominent line of glacial drainage past Pinckney and around the north end of the interlobate spur to the Portage Swamp, in northeastern Jackson County. The kames rise 100 to 150 feet above the gravel plain and are distributed on both sides of Huron River. Those on the north side appear to pertain to the Saginaw and those on the south side to the Huron-Erie lobe. Back of them on either side of the river are bulky moraines, the one on the north being the probable continuation of the Charlotte system of the Saginaw lobe, and the one on the south belonging to the Huron-Erie lobe, which in northeastern Indiana includes the Mississinawa, Salamonie, Wabash, and Fort Wayne moraines, and in Michigan, from a point near the limits of the Ann Arbor quadrangle northward, the Defiance moraine. The kames were probably formed while the lobes were nearly coalesced over the portion of the Huron Valley east of Pinckney, but the moraines back of them appear to have been formed after the lobes had become sufficiently separated to permit glacial drainage to flow between them.

Near Milford, in southwestern Oakland County, as shown on the Milford topographic sheet, another interlocking of moraines indicates that the two lobes were for a time coalesced down to that point while separated along the portion of the Huron Valley just below. In passing through these interlocking ridges Huron River is obliged to make a series of long curves. The ice border after a time shrank away from these interlocking ridges and receded north and south as well as northeastward. As it receded outwash aprons were formed on its borders, those north of Milford being connected with a strong moraine of the Saginaw lobe and those east and south of Milford with the Huron-Erie lobe. A prominent sandy plain east of Milford, known as Commerce Plain because it covers much of Commerce Township, and its continuation down Huron River are both much lower than the outwash plains north of Milford, for the latter are held up by the series of interlocking ridges near that village, through which only narrow gaps lead into the Huron Valley.

Gravel plains, which are extensive from Commerce Township northeastward to Oxford, are crossed or interrupted by two morainic ridges. One ridge, shown on the Pontiac topographic sheet, leads northwestward from Orchard Lake to White Lake and separates Commerce Plain from Drayton Plain. Another ridge runs east from Clarkson village and separates Drayton Plain from Oxford Plain. These ridges connect at either end with prominent morainic belts trending with the gravel plain, the moraine at the north being the Saginaw and that at the south the Huron-Erie. East of Drayton Plain, in the district immediately north and west of Pontiac, a till plain covers about 15 square miles. This is the only conspicuous till plain along the junction of the two lobes, except that in Jackson County, already noted.

From the slopes of the different portions of the gravel plain some inferences have been drawn as to the ice lobes that contributed the principal outwash. The Commerce Plain seems to have been formed by the Huron-Erie lobe, for, as shown on the Pontiac topographic sheet, it has a northwestward slope from the Huron-Erie moraine to Huron River, which follows its northwest edge. Drayton Plain, on the other hand, seems to have been built up largely by outwash from the Saginaw lobe, for it has a southeastward slope from the moraine of that lobe to Clinton River, which follows its southeast border. Oxford Plain seems to have been filled by outwash from the east and the west and the head of the reentrant on the north.

As the ice shrunk back from the north end of Oxford Plain into southern Lapeer County outwash from along its edge filled the low places among the morainic knolls to altitudes nearly 100 feet above Oxford Plain, without, however, covering the principal knolls.

Several prominent kames lie along the line of the moraines on each side of the gravel plain from Milford up to Oxford Township. The most prominent are fully 200 feet in height. Most of them rise above the 1,100-foot and several above the 1,200-foot contour, and one about 6 miles northeast of Oxford appears by aneroid to reach an altitude of 1,300 feet. Oxford Plain is about 1,060 to 1,075 feet at its northern edge, Drayton Plain about 1,000 feet at its northern edge, and Commerce Plain about 940 feet at its eastern edge. The most prominent knoll between Commerce and Drayton plains rises to 1,111 feet. The Pontiac and Rochester topographic sheets indicate that a knoll about 2 miles west of Clarkston reaches 1,201 feet; Pine Knob, 2½ miles east of Clarkston, 1,221 feet; Mount Judah, 6 miles north of Pontiac, about 1,180 feet; and Bald Mountain, 8 miles northeast of Pontiac, 1,195 feet.

TOPOGRAPHY.

The present relief of the divide above the lowlands on either side is only in small part due to drift, for the rock surface of the divide stands fully as high above the rock surface of the lowlands as the present drift surface stands above the lowland drift surface. The drift deposits are generally as thick in the lowlands as on the divide; indeed, in small areas along or near the divide in southwestern Jackson and neighboring parts of Calhoun, Hillsdale, and Branch counties, the drift deposits are insufficient to conceal the rock hills, despite the fact that the hills have but slight relief above the thick drift filling that covers the lower land. In some of these hills the rock attains an altitude of over 1,100 feet above sea level, higher than in any other part of the southern peninsula, but along much of the divide it is only 800 to 900 feet on the hills and ridges and much lower in the drift-filled interspaces. The altitude of the drift surface is highest in two somewhat widely separated localities, one in Hillsdale County where the rock is exceptionally high, and the other in northern Oakland County where the drift aggregation is very great. In both places the maximum altitude is about 1,300 feet and in numerous knolls it is 1,200 feet or more. The drift surface along this divide ordinarily is not far from 1,000 feet above sea level, or about 400 feet above the surface of the neighboring Great Lakes.

STRUCTURE OF THE DRIFT.

THICKNESS.

The thickness of drift is considerably less on the Saginaw than on the Huron-Erie part of this interlobate system, for the Saginaw part lies on the table-land of sandstone belonging to the Marshall formation, and the Huron-Erie part covers the lowland underlain by the Coldwater shale. The general altitude of the rock surface is 150 to 200 feet greater where the sandstone is the upper rock formation than where the Coldwater shale immediately underlies the drift. As the general altitude of the drift surface on the Saginaw side of the interlobate is not much higher (possibly 50 feet) than on the Huron-Erie side, the depth to rock is 100 to 150 feet greater on the Huron-Erie side. Along the ridges of the Huron-Erie lobe it is generally about 250 to 300 feet, whereas on the ridges of the Saginaw side it in few places reaches 200 feet. At the north end of the interlobate system in northern Oakland and southern Lapeer counties the highest ridges may carry 400 feet of drift, for the rock surface at Orion is about 825 feet above sea level and several of the prominent ridges and knolls rise above 1,200 feet.

The sandstone of the Marshall formation underlies a prominent moraine of the Huron-Erie lobe in western Washtenaw County, and its eastern border seems to be within the limits of the Huron-Erie lobe from Washtenaw County southwestward across northwestern Lenawee County and central Hillsdale County. In that portion of the morainic system the thickness of drift is about the same on the Huron-Erie as on the Saginaw side and scarcely reaches 200 feet on the most prominent points. Rock outcrops at a few points in Jackson and Hillsdale counties, but among them the drift generally is 100 feet or more thick.

The amount of drift referable to the Wisconsin invasion is to a large degree undetermined. In places in Washtenaw County in the vicinity of Ann Arbor the change from soft till to hard till, thought to mark the line between Wisconsin and pre-Wisconsin drift, is found at a moderate depth, but more commonly at 100 feet or more. In Hillsdale County evidence of the presence of drift sheets of two distinct invasions is still clearer, beds of black muck or swampy deposits being found at the base of the soft till. A few miles south of Hillsdale this black muck is found in wells over an area of several square miles. It lies about 100 feet below the surface, thus corresponding to the general depth to the hard till on the moraines in the vicinity of Ann Arbor. The surface of the hard till in the vicinity of Ann Arbor appears to be very uneven, the depth to it ranging from a few feet to about 130, either because the topography of the older drift was morainic or because it was carved by interglacial erosion. It is much higher in the prominent morainic ridge leading southwest from Ann Arbor and in a prominent tract east of the city than it is on the lowlands between. In places east of Ann Arbor it comes nearly to the surface on the morainic knolls. From the few data available it appears probable that the pre-Wisconsin drift in this vicinity contained prominent ridges which have not been completely concealed by the Wisconsin drift.

It is thought that the prominent kames along the borders of Huron River near the axis of this morainic system were developed during the Wisconsin ice invasion and that the drift at this latest invasion was built up from a level as low as the bottoms of the basins of the lakes and swamps which abound in this region. Some of these lakes have depths that exceed 100 feet. This fact and the fact that the wells on the borders of the lakes penetrate great depths of assorted material are thought to indicate that the deposition of morainic and outwash material at the last ice invasion has produced all that is found from the level of the bottoms of the lakes to the tops of the bordering knolls. At least no suggestion of a change in the constitution of the drift has been noted.

COMPOSITION.

The drift of the interlobate system in the area in which the ice lobes coalesced changes its texture as it passes back into the districts lying beneath each of the ice lobes. Along the line of coalescence the drift is gravelly and sandy with only scattered deposits of clayey till, the kames are made up largely of gravel and cobble, and the outwash aprons are composed of gravel and

sand. In passing back into the moraines on either side, however, the deposits change first to a loose-textured drift with large numbers of cobblestones in a sandy matrix, and a little farther back to a clayey till similar to that in the moraines outside the interlobate tracts. Commonly several miles is required for the transition, but in places, as, for instance, near Pontiac, a clayey till is found on the immediate borders of the gravel plain. The prominent moraine which leads from Pontiac southwestward past Ann Arbor is characterized by clayey till along much of its course in Oakland and Washtenaw counties. At the northeast it is near the edge of the gravel plain, but toward the southwest it bears away, passing east of an older moraine. On the Saginaw side of the interlobate tract the drift is generally loose-textured nearly to the inner edge of the morainic belt, though it is interrupted in a few places by a stiff clayey till, as, for instance, in the northern part of the interlobate spur west of Portage Lake in southern Livingston County.

In places a thin veneering of a somewhat clayey till thickly set with bowlders overlies gravelly drift of great depth. This is the case on the drift of the Huron-Erie lobe in northern Washtenaw and southern Livingston counties from Whitmore Lake westward to Portage Lake, and in eastern Livingston and northwestern Oakland counties on moraines of the Saginaw lobe.

BOWLDERS.

Bowlders are exceptionally numerous all over the Saginaw portion of the interlobate moraine, there being scarcely a square mile outside the gravel plains in which they are not conspicuous. On the Huron-Erie side of the interlobate system they tend to segregation in belts, though they are generally numerous for several miles back from the edge of the gravel plain. Bowlder belts run usually about parallel to the main ridges, but are not confined to the ridges. Thus one in western Washtenaw County, which has been represented on the map in the Ann Arbor folio, leads southwestward from Dexter midway between two prominent moraines. These belts were probably deposited along the edge of the ice in the course of its recession and may mark brief halts which were insufficient to produce a moraine. The Fort Wayne moraine, which crosses Huron River near Ann Arbor, has remarkably few bowlders on its surface in Washtenaw County compared with the number in outside districts.

Few of the bowlders are more than 5 or 6 feet in diameter and are largely granite. The red jasper conglomerate bowlders are perhaps more conspicuous in this interlobate morainic system than elsewhere in the southern peninsula. Many have been gathered up for dooryard ornaments, and they are frequently worked into the foundations of dwellings because of the attractiveness of the bright-red pebbles. Conglomerates of other kinds are also present in notable amount and quartzites are not rare. On the Huron-Erie portion of the morainic system in Washtenaw and Lenawee counties limestone blocks from the formations at the head of Lake Erie are frequently found; some of them are large.

The rock constituents of the drift are very largely derived from formations within a few miles of the morainic system. The moraines of the Huron-Erie lobe contain limestone from the Silurian and Devonian formations, which outcrop in the southeastern corner of the southern peninsula and in neighboring parts of Canada; the black Devonian shale is also conspicuous. The large amount of clay present in the eastern edge of the moraines of the Huron-Erie lobe may be referable to the accessibility of shale material from the underlying Coldwater shale, as well as to the imperfect drainage conditions.

On the Saginaw portion of the morainic system sandstones, derived in part from the coal measures and in part from the Marshall formation, form a conspicuous part of the coarser rock constituents. Coal is frequently reported from all through the Saginaw part of the morainic system, even from places some miles outside the limits of the coal measure formations. It need scarcely be suggested that the presence of coal in paying quantities should not be inferred from the finding of masses of coal in the drift.

GLACIAL DRAINAGE.

The glacial drainage of the interlobate district is a matter of some interest as it departs considerably from the present lines. It was governed by the bordering ice lobes and only to a slight extent by the slopes of the land surface.

When the ice border stood at Hanover in southern Jackson County the water from the reentrant angle followed South Fork of Kalamazoo River to the bend near Homer in southeastern Calhoun County, where it cut across the narrow space that now separates the St. Joseph and Kalamazoo valleys and entered the St. Joseph Valley. It followed this valley to the great bend at South Bend, Ind., where it passed into the headwater part of Kankakee River and thence to Illinois and Mississippi rivers and the Gulf of Mexico.

When the ice border stood on the north and east sides of Grass Lake Plain in eastern Jackson and western Washtenaw counties the drainage was not northward from Jackson down Grand River but was westward through a series of swampy channels that led across to the Kalamazoo through western Jackson County. It seems to have followed the present course of the Kalamazoo about to the site of the city of Kalamazoo and thence went southward to the St. Joseph Valley near Three Rivers and on to the Kankakee past the site of South Bend.

When the ice border stood near Milford the drainage followed down Huron River about to Portage Lake. From there it continued westward to the Portage Swamp in northwestern Jackson County and thence to the Grand River valley just north of Jackson. After following Grand River to Eaton Rapids it passed westward, as shown on the Lansing topographic sheet, through a swamp now utilized by the Michigan Central Railroad to Charlotte, where it entered Battle Creek. Thence it passed to the Kalamazoo and apparently followed the course of the present river to the site of Plainwell, a few miles below Kalamazoo. From there it seems to have passed southwestward for a time through the low district west of the Kalamazoo morainic system to the head of the Kankakee at South Bend, a part of its course being through long pools or lakes.

With the northward recession of the Saginaw ice lobe the drainage continued down Grand River a few miles beyond Eaton Rapids and then, as shown on the Lansing topographic sheet, passed westward to the Thornapple, which it followed to the bend below Hastings. Thence it passed southward by Gun Lake and down the Gun River valley to the Kalamazoo. It seems to have passed directly across the Kalamazoo Valley and to have reached the headwaters of Paw Paw River in northeastern Van Buren County. Thence it seems to have followed down the Paw Paw Valley to a glacial lake, the incipient Lake Chicago, that filled the lower course of the Paw Paw and St. Joseph valleys at the time when the Lake Michigan lobe extended but little beyond the limits of the present lake. From this small glacial lake the drainage led along the border of the ice to the south end of the Lake Michigan basin (see pp. 226–227) and thence into Desplaines, Illinois, and Mississippi rivers. It is not entirely certain that the drainage from the headwater part of the Huron took this course through the Thornapple Valley; it may have followed the course past Ann Arbor next to be considered.

When the Huron-Erie ice lobe had receded southeastward to the site of Ann Arbor the glacial drainage followed down the Huron Valley, with perhaps a slight deflection south of the valley near Dexter. On reaching the edge of the ice sheet near Ann Arbor it turned southwestward through a large swampy valley (see Ann Arbor folio and topographic sheet) that passes just north of Pittsfield Junction and Saline to the Raisin Valley, in southwestern Washtenaw County. Thence it followed down the Raisin Valley to the vicinity of Adrian, where it entered Lake Maumee, whose outlet led past Fort Wayne, Ind., to the Wabash.

TILL PLAINS.

Among the morainic ridges of the Huron-Erie lobe in Oakland, Washtenaw, Lenawee, and Hillsdale counties narrow strips of till plain have surfaces much smoother than those of the neighboring ridges. The till plains are not continuous, however, for many miles, being broken by the interlocking ridges. Near the State line of Michigan and Ohio the ridges become more widely

separated and the till plains continue distinct for many miles in northeastern Indiana and northwestern Ohio.

One till plain occupying an area of 50 or 60 square miles lies in the southern part of Jackson County east of the Hanover interlobate spur. Its surface is gently undulating, with swells 10 to 20 feet high, but is decidedly smoother than that of the bordering moraine west of it. Bowlders are about as numerous as on the moraine. It is a region of rather thin drift, rock being struck in many places at 30 feet or less. The till is of loose texture and seems to have considerable sand and gravel associated with it.

A narrow till plain 8 to 10 miles long and only 2 or 3 miles wide lies in northern Hillsdale County a few miles northeast of the city of Hillsdale. It is very elevated, the greater part of its surface being between 1,100 and 1,200 feet above sea level. The surface is gently undulating but lacks the sharp knolls and basins found in the neighboring moraines on either side. The drift here is 60 to 100 feet or more in depth and contains considerable clayey till, so that many wells are driven nearly to the rock before obtaining water.

In the southern part of Hillsdale County a till plain on the outer border of the Wabash moraine has a width of about 3 miles and a length of 7 or 8 miles. Its surface is very gently undulating and in places flat. The till is compact and clayey and extends to a considerable depth; wells in it have not reached rock at a depth of 100 feet.

Another till plain in Hillsdale County lies between the Wabash and Fort Wayne moraines. Its southern portion is on the west side of St. Joseph River and its northern portion is west of the headwater portion of Bean Creek. It lies mainly in southeastern Hillsdale County but extends northeastward as a narrow strip a short distance into Lenawee County. It continues between these two moraines down the St. Joseph Valley into Indiana. The till is very clayey and extends to considerable depth.

An extensive till plain lies in the western half of Lenawee County on the east side of the Fort Wayne moraine. Its width is 6 to 8 miles and it runs from the northern edge of the county in a course west of south to the southwest corner. It continues into Ohio and widens southward as indicated in the discussion of the Fort Wayne moraine. At the northern end, in southwestern Washtenaw County, it is cut off by interlocking ridges. This till tract has an undulating surface, in places nearly as uneven as the bordering part of the Fort Wayne moraine. It is composed very generally of a stiff clayey till.

In western Washtenaw County there is a tract covering nearly 100 square miles in which the surface is less definitely ridged than on the bordering morainic tracts to the east and west. It has, however, several large gravel knolls or kames (see Ann Arbor folio and topographic sheet) rising 75 to 100 feet or more above the general level, as well as numerous small knolls, and an esker known as the Lima esker. Marshy basins lie on the interfluvial tracts, and narrow strips of marsh border nearly all the streams. The surface is therefore far from flat and can be called a plain only when contrasted with the neighboring ridges, whose surfaces are a succession of steep hills and ridges. Owing to the loose texture of the drift the roads in dry seasons work into loose sand. The drift contains many small stones 3 to 6 inches in diameter that are apparently scattered through it rather than arranged in definite beds. Bowlders are not rare on any part of the surface and are especially numerous in narrow strips which may properly be termed bowlder belts. One of these (see Ann Arbor folio) leads entirely across the plain from the vicinity of Dexter southwestward to the vicinity of Pleasant Lake, passing near the east end of the Lima esker and running past some prominent kames south of Lima Center.

In northern Washtenaw County strips of till alternate with gravel plains that lead northwestward toward the Huron Valley. The till is as a rule thickly strewn with bowlders, but its surface is comparatively smooth. It ranges from a clayey to a very loose textured deposit.

ESKERS.

CHARACTER AND DISTRIBUTION.

A few elongated gravel ridges of esker type terminate in this interlobate system and numerous short ridges of similar form and constitution which should probably be classed with eskers. The short ones may be passed with the mere statement that they occur at various points in the Saginaw part of the interlobate tract from eastern Livingston County northeastward across northeastern Oakland County. Most of them are only 10 to 20 feet in height, 100 yards or less in width, and a mile or less in length. They commonly lie in swampy tracts, though some of them are on the slopes of the prominent parts of the moraine. They are composed of well-assorted gravel and are often drawn on for road material.

LIMA ESKER.

The Lima esker is the only prominent representative of this class of glacial ridges noted on the Huron-Erie side of the interlobate tract. It is situated 10 to 15 miles west of Ann Arbor in Lima Township, Washtenaw County, along a branch of Mill Creek that forms the outlet of Fourmile Lake. (See Ann Arbor folio.) Its length is about 6 miles, its eastern end being in sec. 24 and its northwestern end in sec. 4, Lima Township. It runs west for about 3 miles and then near Lima Center makes an abrupt turn to the north; aside from this deflection it follows a somewhat winding course, and in one place about 1½ miles north of Lima it describes a letter S. It rests on the uneven surface of the slopes of the valley or depression through which the outlet of Fourmile Lake flows, rising and falling 30 feet or more with the surface on which it lies. Its relief in few places is more than 20 feet, and it is interrupted by several small gaps.

Gravel pits opened in the esker indicate that it was formed by a stream flowing west and north, or in a direction opposite to that of the present drainage. At its northwest end is a sharp gravel knoll about 50 feet high which it is thought may have been built by the same drainage that formed the esker. It seems probable that the esker was deposited at a sufficient height above the base of the ice to correspond with the height of this knoll, though it is possible that water might gush up at the edge of the ice, as was noted by Russell in the Malaspina Glacier, and deposit material there at a level higher than that of the tunnel through which it was flowing.

The material of the esker is not markedly waterworn, and the preservation of fragile pieces of Devonian shale of considerable size in it is thought to indicate that some of the material may have been subjected to but slight transportation after it was released from the ice. The esker development seems to have been the closing event of the subglacial drainage, its material being deposited along the line of the drainage because the stream had insufficient strength to carry it to the ice border.

ACKERSON ESKER.

The gravel ridge to which the name Ackerson esker is applied was noted in the discussion of the interlobate spur in southern Jackson County. (See p. 197.) It seems to stand very near the junction of the Saginaw and Huron-Erie lobes and terminates in the morainic spur formed between them. It passes from the west end of Wolf Lake past Ackerson Lake through a gently undulating till plain and strikes the interlobate spur about 8 miles south of Jackson. Its structure from top to bottom is revealed in a cut on the Cincinnati Northern Railroad near Ackerson Lake. It contains very coarse material—much coarser than is ordinarily found in eskers—reaching a maximum in small bowlders nearly a foot through and slabs 2 feet or more long. The coarse material is quite generally present, especially southwest of Ackerson Lake. The ridge is also more massive than the ordinary esker, being in places about one-eighth mile in width, but it has the abrupt embankment-like appearance and the customary great length of ridges of this class, being nearly continuous for about 7 miles and standing 30 to 40 feet above the border tracts along much of its course. Possibly it is the product of a combination of ice deposition with subglacial drainage, and this may account for the coarseness of its material and for its unusual size.

CHARLOTTE MORAINIC SYSTEM OF THE SAGINAW LOBE.

COURSE AND DISTRIBUTION.

The Charlotte morainic system, which takes its name from the county seat of Eaton County, differs from most morainic systems in having a rather vague outer border, the nearly plane till tract on the south rising gradually, in the space of 1 to 2 miles or more, into a pronounced moraine. A few morainic spurs and some eskers extend southward on to the plain. The topography seems to be such as might result from a mere halt in the recession of the ice border. The large number of eskers leading into it from the inner border plain, and especially those in the midst of the moraine, seems to indicate that the ice was nearly stagnant, and the character of the outwash and the ice-border drainage seem consistent with such an interpretation.

This morainic system connects at the west with the Valparaiso morainic system of the Lake Michigan lobe and is believed to be the full equivalent of that system, though it is less bulky. The outermost ridge of the Charlotte system connects with a ridge of the Valparaiso system at Dias Hill, about 12 miles south of Grand Rapids; a second and stronger ridge connects at the bend of Grand River just north of Grand Rapids; and a third connects near Cedar Springs, about 15 miles north of the same city. This recession of about 24 miles in the reentrant angle between the Saginaw and Lake Michigan lobes is greater than that at any other place along the line of the Charlotte morainic system, the ridges elsewhere being commonly combined into a single belt 4 to 8 miles wide.

The outer ridge leads from Dias Hill, in southern Kent County (see Grand Rapids topographic sheet), southeastward across the northeast corner of Allegan County to Thornapple River at Middleville, in Barry County. The outer edge of the second ridge follows the west side of Thornapple River north from Middleville nearly to Grand River before it crosses the stream. East of the Thornapple the two ridges combine into a single belt which lies along the north side of Thornapple River from Middleville to Hastings. At Hastings the outer ridge crosses to the south side of the river and follows its south bluff past Nashville and Vermontville for 18 miles. A few miles east of Vermontville the second ridge crosses the river, which has been deflected to the south, and the two ridges again combine in a single belt that leads past Charlotte. A short distance east of Charlotte the belt breaks up, as shown on the Lansing topographic sheet, into two and in places three ridges, separated by narrow swampy depressions. Beyond Grand River, however, just below Eaton Rapids, a single broad belt leads eastward across the Mason, Fowlerville, and Howell quadrangles in southern Ingham and southwestern Livingston counties to connect with the correlative morainic system of the Huron-Erie lobe in the Howell and Milford quadrangles in the southeastern part of Livingston and southwestern part of Oakland counties. The combined system of moraines and their included outwash aprons form the conspicuous interlobate belt that leads northeastward across Oakland County into southern Lapeer County. The Charlotte system becomes blended with the inner part of the Kalamazoo morainic system in southeastern Ingham County and has no distinct development farther to the east.

A third prominent moraine that seems referable to this system separates from the other moraines a few miles north of Hastings and leads northward through the southwestern part of Ionia County to Grand River valley just above the mouth of Flat River. It turns westward across Flat River into Kent County and merges with the second moraine of the system. The combined belt connects with a correlative morainic belt of the Lake Michigan lobe near Cedar Springs in northern Kent County. A morainic spur extending from it north-northeast to Greenville may perhaps be considered a part of this third belt. So also may somewhat isolated morainic strips farther north in western Montcalm County. It was probably in connection with the development of the Charlotte morainic system of the Saginaw lobe and the Valparaiso system of the Lake Michigan lobe that the strong interlobate moraine, which was discussed in connection with the Kalamazoo morainic system and which covers much of Mecosta and Osceola counties, was given its surface expression.

TOPOGRAPHY.

Along much of the morainic system, and especially in the portion distinct from the Lake Michigan and Huron-Erie lobes, the topography is of a swell and sag type, with many separate knolls 10 to 20 feet in height and some in groups or chains 50 to 75 feet in height. The relief above the outer border plain is slight, for a basement ridge is generally lacking and the moraine is merely an assemblage of knolls and sags. In the reentrant angles between the Saginaw and Lake Michigan lobes and between the Saginaw and Huron-Erie lobes there are a few very prominent knolls ranging from 100 to 200 feet in height. Dias Hill rises to 1,032 feet, or nearly 200 feet above the surrounding country, in an irregular mass covering scarcely 2 square miles. A range of hills east of Rockford, in north-central Kent County, known as the Prospect Hill Range, is about 100 feet in height, 3 miles in length, and less than one-half mile in width. Another range about 8 miles farther north, lying east of Cedar Springs, is of similar dimensions to the Prospect Hill Range. These are the principal prominent elevations in the vicinity of the Michigan and Saginaw reentrant.

Eastward from the reentrant the first prominent group of knolls is on the east side of Thornapple River. It begins opposite Middleville and extends northward about 7 miles. Its height is about 100 feet above the highest terrace of the Thornapple and in several points exceeds 900 feet above sea level. It trends at a right angle to the moraine and stands in the direct line of continuation of the prominent interlobate spur between the Lake Michigan and the Saginaw parts of the Kalamazoo morainic systems. This relation has suggested the possibility of its being an overridden part of the interlobate spur, though full evidence to that effect has not been found. From 3 to 6 miles east of this range other prominent hills are arranged in small groups whose highest points considerably exceed 900 feet. The surrounding morainic tracts rise to about 850 feet.

Immediately north of Hastings the moraine is traversed by a chain of lakes which leads across it nearly at right angles. Most depressions of this sort have been utilized by rivers as passages, but this one is not so occupied.

The Thornapple Valley, which lies between the two members of the morainic system in eastern Barry and western Eaton counties, is fully 100 feet below the bordering moraines and nearly a mile in average width, yet it seems to have suffered only a small amount of erosion either by the present river or by its fluvioglacial predecessor. It is merely a large depression left by the ice.

The portion of the morainic system south of Thornapple River is deeply indented by long depressions which extend from north to south nearly through it and whose bottoms are but little above Thornapple River. Some short gravelly ridges of esker type lie in these depressions. A similar deep depression traverses the moraine on the north side of the river immediately west of Vermontville, and this also carries esker-like gravel ridges.

From Vermontville eastward across Eaton County to the Grand River valley near Eaton Rapids (see Lansing topographic sheet) the inequalities of surface are due more largely to deep depressions in the morainic system than to prominent knolls, though there is a knoll just north of Charlotte about 75 feet in height and several along the Grand River valley below Eaton Rapids 40 to 50 feet in height. Some of these depressions parallel the trend of the moraine, thus separating it into a system of parallel belts, but some lead directly across one or more of the morainic members. These depressions are largely occupied by swamps. Some have evidently been utilized by lines of glacial drainage, but others still preserve the irregularities of contour left by the ice sheet. In one there is an esker whose southern terminus is at the city of Charlotte. (See p. 209.)

East of Grand River in southern Ingham County (see Mason topographic sheet) the moraines are combined into a single belt, whose borders are very irregular both on the north and the south. The north border is deeply indented by swampy tracts, some of which extend nearly through the morainic belt. Some of these are occupied by eskers which head on the till plain north of the moraine. The south border shows some recesses, one of which contains

the head of the Rives esker system (p. 192) and some spurs extending to the south. Some of these spurs include esker-like gravel ridges, and some small eskers stand between the spurs in the plains just outside the moraine. The range between the tops of the highest knolls and the beds of the deepest depressions is 75 to 100 feet, but few of the knolls are over 50 feet high and most of them are 25 feet or less. Among the knolls are numerous swampy basins, but lakes are not common.

In Livingston County, where the Charlotte system is more or less closely combined with the Kalamazoo, the northern portion of the combined system resembles the Charlotte system in Ingham County. Swampy depressions containing eskers (see Fowlerville and Howell topographic sheets) extend from the till plain southward into the edge of the morainic system and in some places connect with outwash aprons which head well back into the moraine from the south border. The breaks in the moraine thus seem to be due to a combination of subglacial and extraglacial drainage.

The large kames in the midst of the interlobate tract lie, some in the Saginaw and some in the Huron-Erie portion. Some prominent ones, indicated on the Howell sheet, are found near the inner border, as, for instance, a kame 3 miles west of Howell, on which the tuberculosis sanitarium stands, and others 3 or 4 miles northeast of Howell. Three kames west and south of Chilson reach the 1,100-foot contour, rising about 150 feet above the bordering country. In the northeastern portion of Livingston County, in Tyrone and Hartland townships, the inner part of the moraine is very prominent; points in central Tyrone Township rise above 1,200 feet and considerable areas in both townships rise above 1,100 feet, though the neighboring plains on the inner border rise to less than 1,000 feet. This prominent part as well as the lower part in the western portion of the county is traversed by deep swampy depressions, some of which pass entirely through to the lines of glacial drainage leading into the interlobate gravel plains. On the inner border of the morainic system, northeast and east from Howell, till plains with an area of 2 to 6 square miles are nearly surrounded by tracts with a hummocky topography, like the neighboring moraine. The conditions are so complex both in the moraine and on its inner border that it is difficult to set forth the details, but reference to the topographic sheets will serve to make many features clear. The leading features of the interlobate system in Oakland and southern Lapeer counties have already been discussed. (See pp. 196–199.)

STRUCTURE OF THE DRIFT.

Along the entire length of the morainic system the drift is exceedingly variable. In the more subdued portions the knolls are commonly capped with till, but in many places excavations show them to have a nucleus or pocket of gravel and sand; little of the surface material shows a stiff clayey constitution, though a large part of it would be classed as till rather than as assorted material. The prominent portions of the moraine are made up very largely of assorted material and are to be classed as kames and eskers. This morainic system includes, perhaps, more small eskers than any other in Michigan, and it receives the southern termini of some of the most conspicuous eskers of the State. Some of the esker ridges have a nucleus of gravel and sand with a thin capping of till, a feature which suggests that they were formed near the base of the ice sheet at a horizon low enough to permit the deposition of the englacial material on them.

The amount of assorted material along the line of this morainic belt is such that wells may easily be obtained at moderate depths nearly everywhere. In Ingham and Eaton counties, however, where the drift is of moderate depth, it is customary to continue the wells into the underlying sandstone, for the water there obtained is softer than that from the drift formations.

The thickness of the drift is from 40 to 75 feet along much of the moraine in Eaton and Ingham counties, but is much greater in Livingston and Oakland counties. In Kent County the distance to rock is moderate in the vicinity of Grand Rapids and also near Lowell, but elsewhere the rock surface lies so low that wells have not reached it.

OUTER BORDER DRAINAGE.

At the time the Charlotte morainic system was forming the drainage appears to have been westward from the interlobate tract in Oakland County through a chain of swamps and partly gravel filled valleys along or near the outer border of the system as far as Charlotte and thence down Battle Creek to the Kalamazoo. The drainage left Huron River near the bend at the line of Livingston and Washtenaw counties and passed westward by Pinckney and Anderson and Unadilla to northeastern Jackson County into the Portage Swamp, which emptied into Grand River a short distance north of Jackson. It followed the general course of Grand River valley to a point immediately east of Eaton Rapids, though it was perhaps deflected northward for a short distance through a sandy tract known as the Montgomery Plains, for the present river immediately south of this sandy tract flows in a very narrow valley which does not appear to have carried the glacial drainage and which was probably occupied by stagnant ice. Beyond Eaton Rapids the ice still blocked the channel, and the glacial waters (see Lansing topographic sheet) flowed westward through the swamp traversed by the Michigan Central Railroad between Eaton Rapids and Charlotte. Numerous tributary lines of glacial drainage led southward from the edge of the Charlotte morainic system in Livingston and Ingham counties to join this main line of drainage.

The glacial drainage seems to have had a good gradient only in Oakland County, for in southern Livingston, northwestern Washtenaw, northeastern Jackson, southwestern Ingham, and southern Eaton counties there is scarcely any descent. The altitude of the gravel plain in southern Livingston County is between 900 and 920 feet, much of it being less than 910 feet. That of the Portage Swamp in northeastern Jackson County appears also to be fully 900 feet. That of the Montgomery Plains east of Eaton Rapids, where the glacial drainage seems to have made a detour to the north of the Grand River valley, is above 900 feet and that of the swamp between Eaton Rapids and Charlotte is 900 to 903 feet in its western portion, as shown by the Lansing topographic sheet. In passing down Battle Creek very little descent seems to have been made in the first 10 miles, there being a channel marking an old detour of the glacial drainage to the west of the present stream past Olivet station, whose floor is 885 to 890 feet. Rapid descent begins south of Olivet station, the channel floor being 870 feet at Bellevue and about 825 feet at the city of Battle Creek, 12 miles below Bellevue. The distance having a very low gradient is about 75 miles, and the amount of fall is scarcely 20 feet. It is probable, therefore, that the waters were ponded, but were in sufficient volume to give a strong current through to the lower portion of Battle Creek. With the exception of the Portage marsh in northeastern Jackson County, where the water may have spread out to a width of 3 or 4 miles, the topography is such as to indicate that the width generally throughout this 75 miles of ponded drainage was scarcely more than a mile, and in places it must have been reduced to less than one-half mile. The course of the glacial drainage just outlined could not have been different under the conditions of altitude that obtained in the region while the ice was filling the portion of the Grand River valley below Eaton Rapids. To have passed through any of the channels utilized during the development of the Kalamazoo morainic system the waters would have been compelled to rise to about 960 feet.

From the city of Battle Creek the glacial drainage followed down the Kalamazoo Valley to the vicinity of Plainwell, descending from 825 feet to 750 feet in about 35 miles. Thence the drainage took a southwestward course through the low plain west of the Kalamazoo morainic system, descending to about 725 feet in the vicinity of Dowagiac. There a narrow lake (Lake Dowagiac) seems to have extended from Dowagiac to South Bend, Ind., from which the discharge was southwestward along the Kankakee to Illinois and Mississippi rivers and the Gulf of Mexico.

From the portion of the border of the Charlotte morainic system west from the meridian of Charlotte the drainage was inconspicuous to the vicinity of Hastings, but from that city up to the reentrant angle near Dias Hill in southern Kent County it was large, producing a broad outwash apron whose altitude in the reentrant angle between the Saginaw and Lake Michigan

lobes is about 800 feet. The waters passed southward along the eastern front of the Lake Michigan lobe to Plainwell and there joined the longer line of glacial drainage just described.

With the northward extension of the reentrant angle between the Saginaw and Lake Michigan lobes, past the city of Grand Rapids, and a slight westward shrinkage of the border of the Lake Michigan lobe a line of glacial drainage with bed below the 700-foot contour, well shown on the Grand Rapids topographic sheet, was opened southward from Grand Rapids past Carlisle and Ross to Rabbit River.

With the recession of the reentrant into southwestern Montcalm and southeastern Newaygo counties the glacial drainage took a southward course between the ice lobes for a short distance and then turned into districts which had just been abandoned by the Lake Michigan lobe. (See pp. 220–221.)

INNER BORDER.

GENERAL CHARACTER.

The interval between the Charlotte morainic system and the next later moraine of the Saginaw lobe is filled principally by a till plain, whose surface is in large part very smooth and much of which is included in the Lansing, Mason, Fowlerville, and Howell quadrangles. In Ingham and Livingston counties, however, it is traversed by several eskers, which lie for the most part in shallow swampy depressions or esker troughs and which lead somewhat directly toward and terminate in the morainic system. Some of these swampy depressions are not occupied by eskers or are occupied by them for a part of their course only.

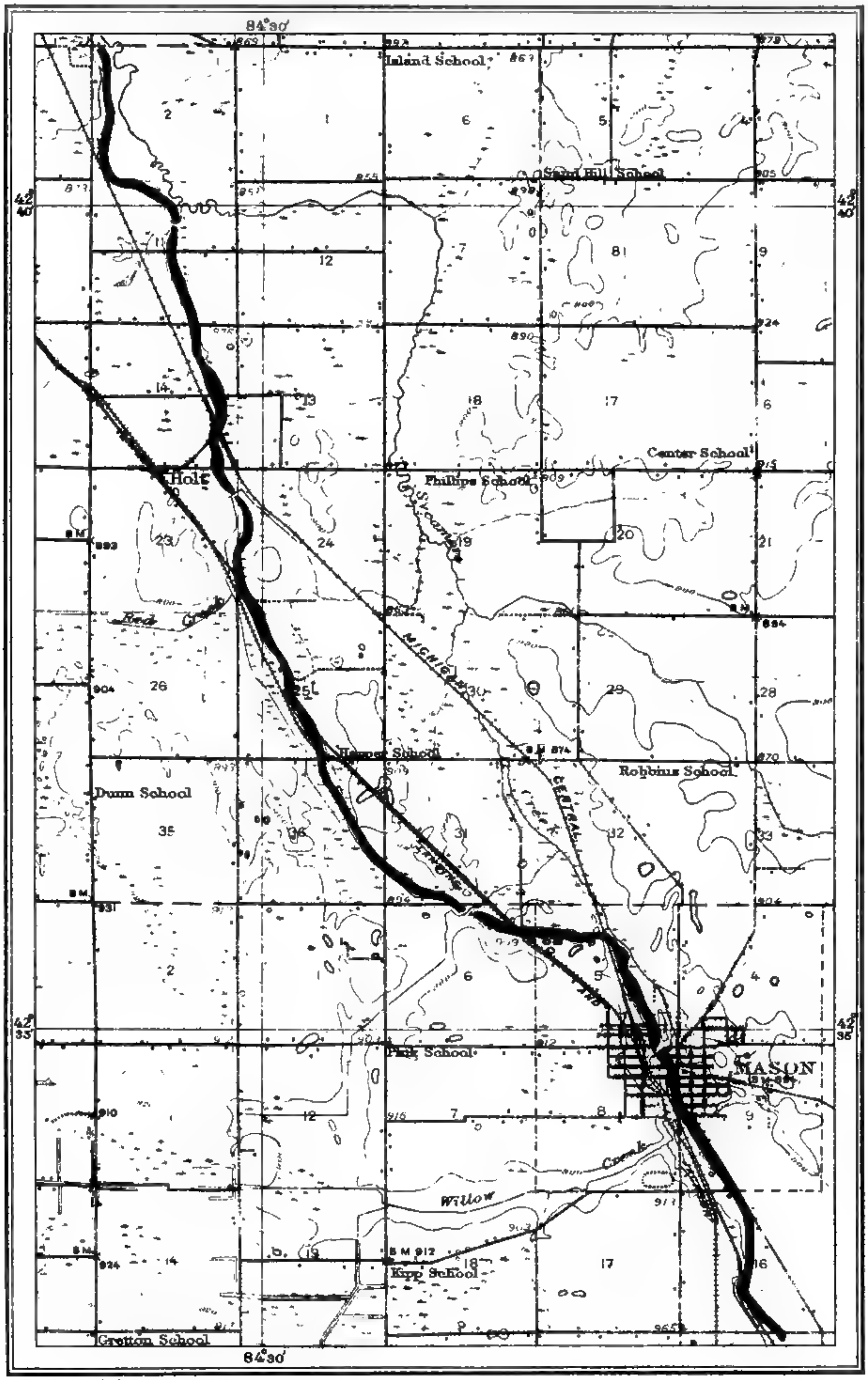
On this inner border tract there are a few very prominent knolls and some undulating strips nearly surrounded by till plains. Some of these knolls northeast of Howell are elongated in the direction of ice movement and form short chains, as is the habit with eskers, but are irregular in shape, in some places reaching a width of nearly one-fourth mile. They are clearly shown on the Howell topographic sheet in secs. 16, 17, 20, 21, 28, and 29, Oceola Township. Though composed largely of gravel and sand they are partly veneered with bowldery till. Their height is from 60 to 100 feet. The longest chain, which extends from the north part of sec. 16 southwestward into the edge of sec. 20, has a length of about 1½ miles. The chain in secs. 21 and 28 is less than a mile in length and so also is the chain in sec. 29.

A rather conspicuous undulating strip about a mile wide with swells 10 to 30 feet high runs east and west through northern Barry and Eaton counties a few miles south of Grand River, Roxana being on it. In places it is nearly in contact with the Charlotte morainic system and in places is separated from it by a till plain 2 to 5 miles wide, and it appears to merge at both ends in that morainic system. Farther east in northwestern Ingham County an undulating strip leads from the Charlotte morainic system at the bluff of Grand River northeastward past Holt to the Cedar Valley east of Okemos. The knolls in it are, however, low and scattered and parts of the strip are difficult to differentiate from the bordering till plains. These strips have in places some resemblance to the slender and in places ill-defined members of the next morainic system, and may perhaps belong with that system.

The surface of this inner-border tract is generally plane, but wells indicate that the underlying bedrock surface is very uneven, the depth to rock ranging from 20 feet or less to about 200 feet.

DISTRIBUTION OF ESKERS.

As already indicated, small eskers a fraction of a mile in length are found in many of the transverse depressions which characterize this morainic system from the vicinity of Hastings eastward across Eaton, Ingham, and Livingston counties. Other longer eskers or esker systems lead from the inner border district southward into the morainic system. These long eskers lie in valleys or troughs throughout much of their courses in the till plain as well as in the moraine. These valleys or troughs are in places nearly as narrow as the esker ridge, but commonly they are several times as wide. Some of the depressions are occupied for only a portion of their length by an esker; the association of esker ridge and trough is, however, so close as



Base from U. S. G. S. Lansing and Mason atlas sheets

MAP SHOWING ESKERS NEAR MASON, MICHIGAN

Scale $\frac{1}{62500}$

Contour interval 20 feet.

Datum is mean sea level.

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to render it probable that they owe their origin to the same agency—subglacial drainage. In a few places two eskers unite to form a single ridge. (See pp. 211–212.) All eskers of sufficient length are represented on the glacial map and will be considered in turn from Charlotte eastward. Eskers only a fraction of a mile in length will be passed over with a mere mention.

CHARLOTTE ESKER.

This esker, which has its terminus at the eastern edge of the city of Charlotte, is about 9 miles in length. Its northern end is in sec. 3, Benton Township, on the north side of the Thornapple River valley. The river passes across its line in the edge of secs. 10 and 15. The esker follows up the south fork of Thornapple River to the Grand Trunk Railway, about 1½ miles southwest of Potterville. Thus far the esker is represented by short ridges separated by gaps nearly as long as the separate ridges, but from the railway southward, across sec. 34, Benton Township, it is more nearly continuous as a low winding ridge 15 to 20 feet in height and 90 to 100 yards in width at its base. A few short spurs lead from it to the border of the trough in which it lies. In Eaton Township it is well developed in the north part of sec. 4; for the next mile southward it is much interrupted; and after this it is again continuous for a mile or more. Its southern terminus is a well-defined fan-shaped sandy delta which covers about 3 square miles immediately east of Charlotte. Wells in this delta penetrate a fine gravel with much sand intermixed throughout its entire depth to the underlying sandstone. The sandstone has an uneven surface, the depth to it ranging from 16 to 60 feet.

Slight excavations in the esker near its north and south ends show it to be composed mainly of gravel of medium coarseness. The pebbles are largely sandstone of local derivation.

The well-defined trough, in which the esker lies from its head to its southern end, shows a slight descent to the Thornapple Valley and then a slight rise to the delta at Charlotte. At its lowest part its altitude is about 850 feet above sea level, and at the esker fan it is approximately 900 feet. Its depth is from 10 to 20 feet and its width from one-eighth to one-fourth mile. It passes entirely through the Charlotte morainic belt, the esker fan being at the outer edge of the moraine, and it is in the moraine except for 2 or 3 miles at its northern end, where it is in the inner border till plain.

MASON ESKER.

Investigation.—The Mason esker (see Pl. VIII), which passes through the city of Mason, the county seat of Ingham County, and the Williamston-Dansville esker (see Pl. IX), which lies a few miles farther east, were each described briefly by C. C. Douglas [1] in 1839, being among the first of this class of ridges to be described in North America. The Mason esker was also briefly described by L. C. Wooster [2] in 1884. The Mason and Charlotte eskers were studied by the writer in the fall of 1887, and the description here given of the Mason esker was prepared by him in the following winter but was never submitted for publication.

Extent.—The Mason esker is the longest yet observed in Michigan, its length being not less than 20 miles. Cemetery Hill, a prominent gravel knoll 2 miles southeast from the statehouse at Lansing, near the mouth of Sycamore Creek, may be regarded as its northern terminus. This hill rises about 60 feet above the bed of the creek on the west and 30 feet above the valley on the east; a few gravelly knolls to the east and northeast form an indefinite northward extension. Its southern terminus is in the Charlotte morainic system southeast of Mason. For its entire length it lies in a well-marked trough.

Esker trough.—For about 3 miles south from Cemetery Hill the esker follows a depression, one-fourth to one-half mile wide, in which Sycamore Creek flows. About 1½ miles north of Holt, however, the creek bends abruptly, and the esker trough leaves the creek valley and remains distinct from it for 7 or 8 miles. The esker trough in places has a width of half a mile and a depth of 25 to 30 feet, but within the space of a mile it may contract to 100 to 150 yards or may become so shallow that it is difficult to trace. For about 5 miles it maintains

[1] Second Ann. Rept. First Michigan Geol. Survey, 1839, p. 67.

[2] Kames near Lansing, Mich.: Science, vol. 3, 1884, p. 4.

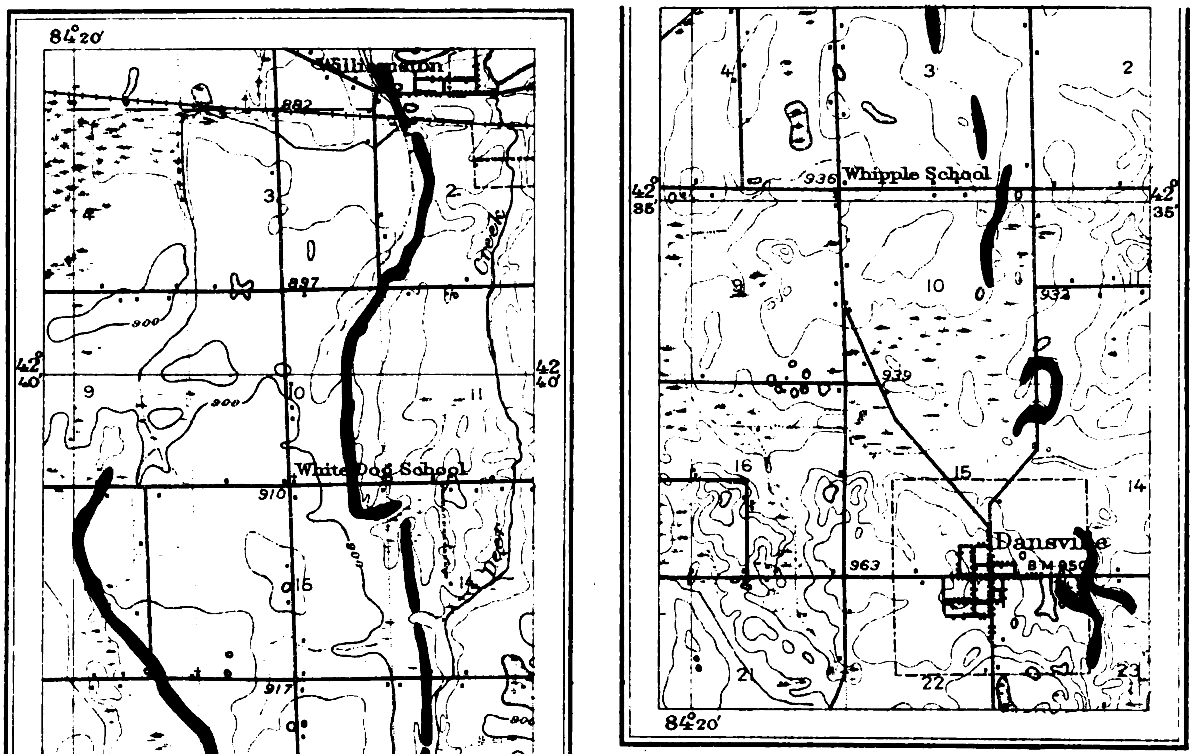
a uniform course approximately S. 20° E., then changes abruptly to about S. 70° E., and so continues for 2 miles or more, when it reunites with the valley of Sycamore Creek. For 3 miles the united valley takes a course fluctuating between S. 20° E. and S. 30° E.; then it changes and runs S. 50°-70° E. to the Mud Creek valley at the inner border of the Charlotte system where it swings abruptly south and follows the creek to its source in the northeast part of Leslie Township (T. 1 N., R. 1 W.). Its form changes with its trend, being deepest where it runs S. 20° E. and shallowest where it passes eastward to join the Sycamore Creek valley; it deepens again when combined with the Sycamore Creek valley but shallows in crossing over to Mud Creek.

Topography.—In the first 3 miles of its course the esker consists of short ridges interrupted by longer gaps, one of which, 2 miles south of Cemetery Hill, gives passage to Sycamore Creek. Farther south, beyond the point where the esker trough reunites with the Sycamore Valley, the esker makes several abrupt turns but keeps within the limits of the valley. (See Pl. VIII.) Its interruptions are slight, apparently aggregating scarcely one-sixth of the combined length of the constituent ridges. The height of the ridges varies considerably and in places changes abruptly, dropping off in a few yards from 40 feet to less than 10 feet and even terminating abruptly to reappear within a few rods as a low ridge. On account of these abrupt breaks it has been used as a wagon road for but a short distance. Its width is only 50 to 100 yards even when highest, and its slopes are very steep, reaching 30° in places. The ridge is especially prominent where it makes the eastward deflection to come back to Sycamore Creek near Mason, its height being 20 to 30 feet above the bordering till plains. The esker passes directly through the city of Mason, where, for a short distance, it lies well up on the east slope of the valley, and rises above the bordering upland. For about 2 miles south of Mason it is 30 to 40 feet in height and practically continuous. After leaving Sycamore Creek in secs. 21 and 22, T. 2 N., R. 1 W., it is low and interrupted by gaps for a mile or more, but on the swampy divide between Sycamore and Mud creeks it is broken by only narrow gaps. In the vicinity of the Charlotte morainic system it expands into a series of kames or plexus of ridges which inclose swampy depressions. Around the southern end of this kame plexus the moraine itself is exceptionally gravelly over an area of about 10 square miles, a feature which is perhaps due in part to the same subglacial drainage that produced the esker.

The course of the subglacial stream which formed the esker, as is shown by the bedding of the gravel, was from north to south, or the reverse of the present drainage, and the elevation of the esker trough increases in passing from the head southward, being about 830 feet near Lansing, 900 feet at Mason, 11 miles up Sycamore Creek, and about 915 feet at the southern terminus 7 or 8 miles farther south. It therefore ascends about 85 feet in less than 20 miles. If the gravelly portion of the moraine adjacent to the southern end of the esker trough be included the rise is 50 to 75 feet more, to the summits of the most prominent knolls. This rise is made abruptly, in places in less than one-half mile. It is doubtful if the stream which formed the esker and esker trough really made such an ascent. The esker trough seems likely to be a result of depletion of the basal portion of the ice by streams within the ice rather than beneath it. If so, the streams may have made little or no ascent.

Composition.—The esker, wherever opened, is composed of stratified and more or less perfectly assorted material. It gives evidence of the action of a stream which varied greatly in the rapidity of flow in different places along a given horizon, both longitudinally and from side to side, as well as at different horizons. The phenomena displayed are not unlike those found in the beds of existing streams flowing subaerially. The esker is evidently a stream-bed deposit, though probably deposited within ice walls.

The most extensive excavation is a railway gravel pit about a mile south of Mason. The esker here has a height of 35 to 40 feet and a breadth of only 50 to 75 yards at the base. The excavation is about one-fourth mile in length and passes obliquely through the esker, its southern end showing the structure of the east side and its northern of the west side, the main part of the exposure being in the elevated central portion. The eastern slope is underlain by fine sand but the main body of the ridge is of gravel. It has a capping of brown clayey gravel, varying



Base from U. S. G. S. Mason atlas sheet.

Eskers

MAP SHOWING THE WILLIAMSTON-DANSVILLE ESKER
INGHAM COUNTY, MICHIGAN

Scale $\frac{1}{62500}$

1 ½ 0 1 2 Miles

Contour interval 20 feet.

Datum is mean sea level.

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in depth from a few inches on the crest to several feet on the less abrupt portions of the slope. The longitudinal vertical section shows that the beds both of the sand and the gravel have a nearly horizontal stratification, though they arch and sag slightly at intervals. Cross-bedding occurs only in thin beds and is not extensive. A transverse section near the southern end of the gravel pit shows evidence of gouging and subsequent refilling; the gravel beds break off suddenly on the east to a depth of 15 feet or more and are replaced by sand. In places the gravel has been taken away completely by the railway company and only a nearly perpendicular wall of sand remains. The sand beds dip rapidly toward the eastern edge of the ridge, but the gravel beds are nearly horizontal.

The coarse pebbles, cobbles, and bowlderets in this esker, as well as in others studied in Michigan, are mainly of local rock material, which here is a sandstone of Carboniferous age. The finer pebbles are less conspicuously local and embrace rocks of various classes. Increase in angularity is accompanied by decrease in size, large pebbles being well rounded and pebbles one-half inch or less in diameter more or less angular. Of 91 pebbles whose diameter averages less than one-half inch, 32 were of crystalline rocks, largely granites, and the remaining 59 were sandstone, limestone, and chert, principally of local derivation. Of 374 pebbles classified whose diameter averages less than one-fourth inch, 134 were of crystalline rocks and the remaining 240 of the same classes as those of the other group. Much significance is attached to the fact that the coarse pebbles are so largely of local derivation; for if, as some suppose, eskers were formed by superglacial streams, they would have contained less local material (this being for the most part beyond their reach), and the coarse rocks would be largely of granites and other distantly derived material which had been brought to the surface by ablation.

Several small gravel pits revealed features similar to those in the large pit. In some of them—for example, in the pit on the line of secs. 9 and 16, Vevay Township—the gravel beds showed a marked southward dip. In the pit at Holt station the beds dip perceptibly toward the eastern edge of the ridge.

In the plexus of ridges at the southern end of the esker more or less clay is mixed with the sand and gravel, and in places the material exposed appears to be partly assorted till. The flow of water seems to have been less vigorous than in the linear portion of the esker.

WILLIAMSTON-DANSVILLE ESKER SYSTEM.

The Williamston-Dansville esker system (see Pl. IX) consists of a main chain of ridges leading from near Williamston, Ingham County, southward past Dansville, a distance of about 10 miles, and of two tributary chains of ridges, one leading southeastward from sec. 16, Wheatfield Township, to join the main chain at the Deer Creek valley in sec. 27, a distance of about 3 miles, and the other following the valley of Doan Creek in a course west of south from sec. 19, Leroy Township, to sec. 23, Ingham Township, a distance of 8 miles. This last chain is interrupted by a gap of fully 2 miles in the northeast part of Ingham Township. A plexus of sharp gravel knolls is developed at the southern end of the esker system, which is at the northern edge of the Charlotte morainic system.

A portion of this esker system, as already noted, was studied by C. C. Douglas[1] about 1839. The present writer studied the southern part in 1887 but did not trace out the esker system completely until the summer of 1900.

The main esker heads a mile west of Williamston near the south bluff of Cedar River in a prominent ridge 30 to 35 feet high. This follows the west side of the Deer Creek valley southward through sec. 2, Wheatfield Township, but takes a more direct course west of it in secs. 10 and 15. In the last two sections its general height is 15 to 25 feet, but in sec. 15 it consists only of a string of knolls broader than the ridge. For the next 2 miles it follows the Deer Creek valley along the line of secs. 22 and 23, 26 and 27, reaching a height of 50 feet in places in the second half of the distance. In sec. 34 it continues prominent, ascending about 30 feet from the creek valley to a till plain on the east, above which it rises 25 to 30 feet. In the south part of sec. 34 it descends into a swampy sag or esker trough and follows it past Dansville to

[1] Op. cit., p. 67.

the edge of the Charlotte morainic system. The border tracts are more undulating and bowldery from about a mile north of Dansville southward than they are farther north. As a rule, this main esker consists of a single string of ridges, but about a mile north of Dansville, where the main ridge curves to the east, describing nearly a half circle, small ridges run across the arc in line with the general course of the esker. Its height is from 15 to 30 feet in the vicinity of Dansville. In the plexus of knolls at the southern end of the esker points reach 50 to 75 feet above neighboring swamps. The knolls here contain some till as well as gravel, but the esker seems to be composed entirely of gravel and sand.

The branch in Wheatfield Township lies in a till plain and is not accompanied by a trough or sag. It is exceptionally regular and smooth and has a height of 15 to 20 feet and rather steep sides. It has no delta at its southeast end, but terminates on the bluff of Deer Creek, one-half mile or more from the main esker. So far as exposed by gravel pits it shows a fine material, some parts being sandy, but most being coarse enough for road ballast.

The branch along Doan Creek has a few ridges strung along in secs. 19 and 30, Leroy, and secs. 25 and 36, Wheatfield townships, with only short interruptions. Then it is broken by a gap of over 2 miles, though the swampy esker trough persists. Near the center of sec. 13, Ingham Township, a ridge sets in and runs southwestward, with but slight breaks, for about 2 miles to the intersection of the main esker. In the last mile it is bulky and irregular, but elsewhere it is a low and narrow ridge and is of typical esker form. The best exposure is in a gravel pit in sec. 36, Wheatfield Township, where a ridge 30 feet high is opened from top to bottom and exposes gravel suitable for road ballast for its entire depth.

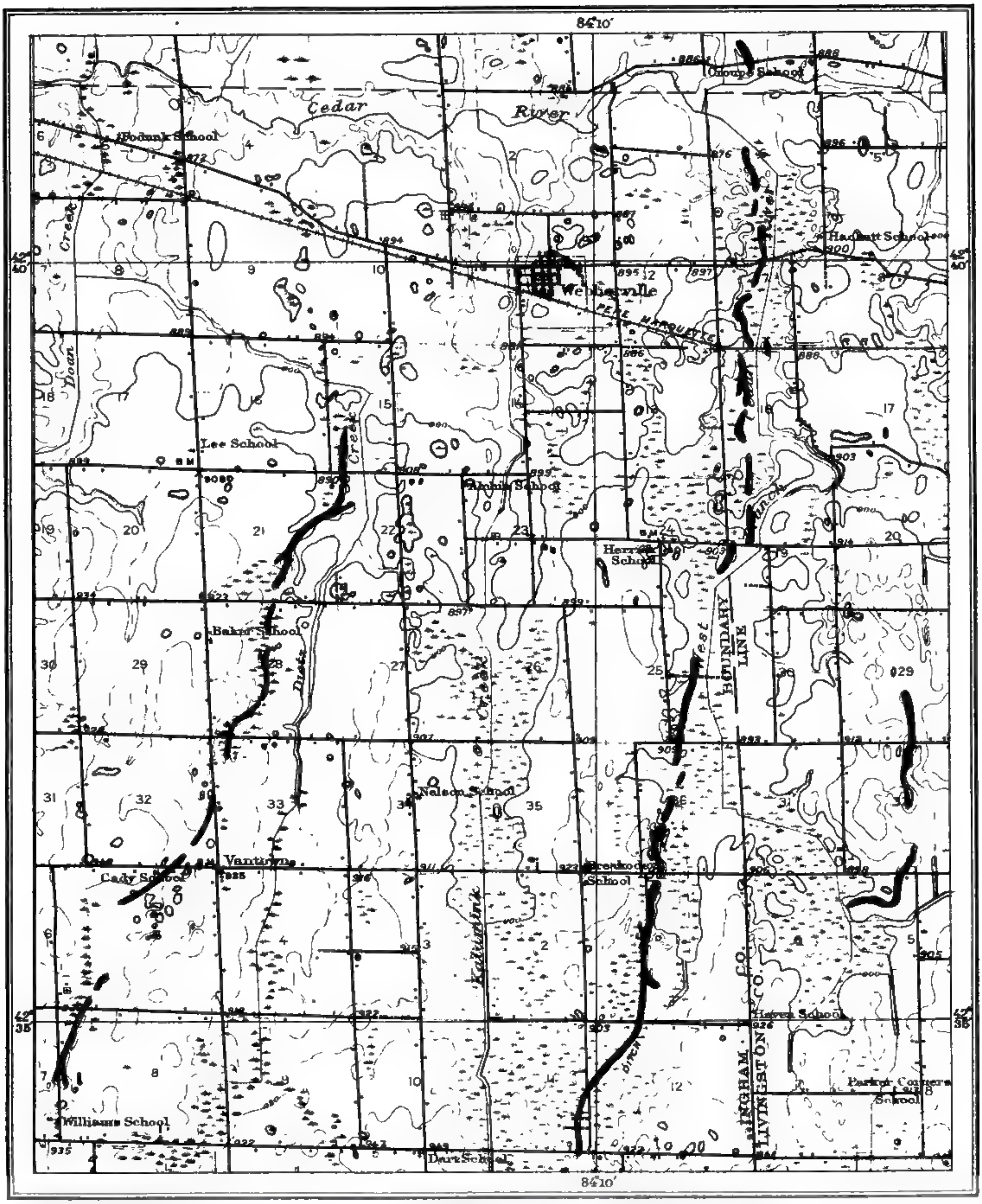
LEROY TOWNSHIP ESKER.

In Leroy Township, in eastern Ingham County, an esker about 5 miles long lies 2 to 2½ miles east of the east branch of the Dansville esker and trends nearly parallel with it from north-northeast to south-southwest. It heads in the southwest part of sec. 15 and follows a small tributary of Doan Creek through secs. 21, 28, and 33, much of the way in a swampy sag. It has a general height of 12 to 15 feet and the steep slopes characteristic of the normal esker. Its continuation on the till plain in sec. 32, Leroy Township, and the north part of sec. 5, Whiteoak Township, is rather faint, but it reappears in strength in the southwest part of sec. 5 and runs across the corner of sec. 6 into sec. 7 to the border of the main moraine of the Charlotte system. In constitution this esker is more sandy than the Mason and Williamston-Dansville esker systems.

ESKER SYSTEM OF WESTERN LIVINGSTON AND EASTERN INGHAM COUNTIES.

An esker system begins in the Cedar River valley in the southwest corner of Conway Township, Livingston County, and runs southward about 3 miles along the valley of the west branch of the Cedar one-fourth to one-half mile east of the Ingham-Livingston county line. (See Pl. X.) Its trough then bears west of south into the edge of Ingham County, but is devoid of esker ridges for about 1½ miles. In sec. 25, Leroy Township, however, ridges set in which are nearly continuous for 3 miles, in secs. 25 and 36, Leroy, and secs. 1 and 11, Whiteoak townships, Ingham County, ending in the middle of the east edge of a large tamarack swamp. The swamp is about 7 miles long and three-fourths to 1 mile wide, extending from sec. 26, Leroy Township, southward across sec. 26, Whiteoak Township. It extends back into the main moraine of the Charlotte system a couple of miles, but seems to have no esker ridges in it, the main esker terminating a mile or more north of the moraine.

A single segment of the esker about 15 feet high and nearly one-half mile long lies north of Cedar River in a marshy tract just south of a moraine in sec. 31, Conway Township. A space of nearly a mile separates it from the next segment to the south in sec. 6, Handy Township. From sec. 6 to sec. 19, Handy Township, it is nearly continuous and has a height ranging from 5 to 40 feet. It is double for a short distance near the Pere Marquette Railroad and incloses a small basin. It does not follow the sag or esker trough, but lies between the trough and Cedar River on a till plain that stands about 20 feet above the river. The portion in Ingham County is in places double or even treble, ridges being nearly parallel to one another and separated



Base from U. S. G. S. Fowlerville atlas sheet

MAP SHOWING ESKERS NEAR WEBBERVILLE, MICHIGAN

Scale $\frac{1}{62500}$

1 ½ 0 1 2 Miles

Contour interval 20 feet.

Datum is mean sea level

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by narrow swampy tracts. There are also slight offshoots in places, a few rods in length. The greatest complexity is found in sec. 1, Whiteoak Township. The height of the ridges ranges from 15 feet to about 40 feet.

The portion of the esker in Livingston County is of coarser material than that in Ingham County; in Livingston County cobble is in places mixed with the gravel, and in Ingham County sand is mingled with it.

IOSCO ESKER.

About 2 miles east of the southern part of the esker system just described a disjointed chain of short eskers leads west of south from sec. 29, Handy Township, to sec. 19, Iosco Township. The portions in secs. 29 and 32, Handy Township, are in the midst of an isolated tract of knolls that lies north of the Charlotte morainic system, its southern end being separated from the inner border of the moraine by a till plain over a mile in width. In sec. 5, Iosco Township, the esker runs out onto this till plain and is broken by a marshy gap about a mile in width. It reappears in sec. 7, Iosco Township, and continues as disjointed ridges as far south as sec. 19, where it terminates in the midst of the Charlotte morainic system with a small sandy expansion, possibly a delta.

OAK GROVE-HOWELL-CHILSON ESKER SYSTEM.

The Oak Grove-Howell-Chilson system is apparently a combination of two and possibly three eskers in an end-to-end series. (See Pl. XI.) The southernmost and probably the oldest leads from near Howell Junction or Ann Pere southward toward Chilson, but the depression in which it lies continues northward past Thompson Lake in the east part of Howell to the southern end of another well-defined esker which extends along the valley of Bogue Creek for 4 or 5 miles. Beyond a space of a mile or more along Bogue Creek is without esker ridges, but at Oak Grove a chain of esker ridges begins and is traceable northward for 2 miles.

The combined length of the series is 14 or 15 miles. The portion between Howell Junction and Chilson consists of disjointed ridges for about a mile, but from near the center of sec. 7, Genoa Township, a nearly continuous ridge extends to the east part of sec. 19. It is very winding in its course through sec. 18, but maintains a general trend about S. 20° E. Its height ranges from 10 to 20 feet and its width from 50 to 75 yards. Near its southern end a fanlike expansion plane, except for basins and surrounded by an extensive swamp a few feet lower, covers the southwest part of sec. 20. The swamp in turn is surrounded by prominent morainic hills, and the morainic topography extends north nearly to Howell along the east side of the esker. In the line of continuation of this esker system, and possibly related to it, in the portion of the moraine west and southwest of Chilson, there is a chain of prominent kames, three of which reach 1,100 feet and a fourth 1,060 feet above sea level. The esker trough reaches 920 to 950 feet in the portion south of Ann Pere.

The esker along Bogue Creek has a fanlike expansion at its southern end, in sec. 25, Howell Township, where also it is developed into a plexus of ridges. With this exception it is generally a single ridge, though in parts of sec. 19, Oceola Township, it consists of two parallel ridges side by side. The sag or depression followed by the esker is swampy along much of its length, though in places Bogue Creek has cut down sufficiently to drain the swamp. This swamp is at the western edge of a complicated network of swamps that covers the western third of Oceola Township and appears to mark the lines of subglacial drainage in the plain north of the great interlobate moraine whose inner border comes up to Howell. These features are shown quite clearly on the Howell topographic sheet. Several exposures on the borders of these sloughs and swampy tracts show a thin deposit of till resting on sand and gravel and possibly consisting of englacial material deposited during the withdrawal of the ice and the contemporary deposition of the esker ridge.

Most of this esker along the Bogue Creek valley is not regular but is bead-shaped—bunched up in places connected by very weak, low ridges. Parts of it, however, in sec. 18, Oceola Township, form typical esker ridges 10 to 20 feet high. On the line between sec. 12, Howell Township, and sec. 7, Oceola Township, the ridge is 30 to 40 feet high and in places nearly one-

eighth mile wide. In sec. 19 it is banked against the west side of the valley and rises 60 feet above the swamp on the east but only 10 to 15 feet above the plain on the west. The plexus of ridges and the bordering sandy plain in sec. 25, Howell Township, seem to form the natural terminus of this section of the esker.

The northern section near Oak Grove is complex in the vicinity of the Bogue Creek mill pond in the eastern part of the village, three ridges converging on the north side of the pond and one of them continuing southward along the east side and terminating without an esker fan at the north edge of a weak moraine. Esker ridges continue for 2 miles north of Oak Grove, but they are interrupted by wide gaps. The district, like that in western Oceola Township, is full of swampy channels which were probably lines of subglacial or glacial drainage.

HARTLAND ESKER.

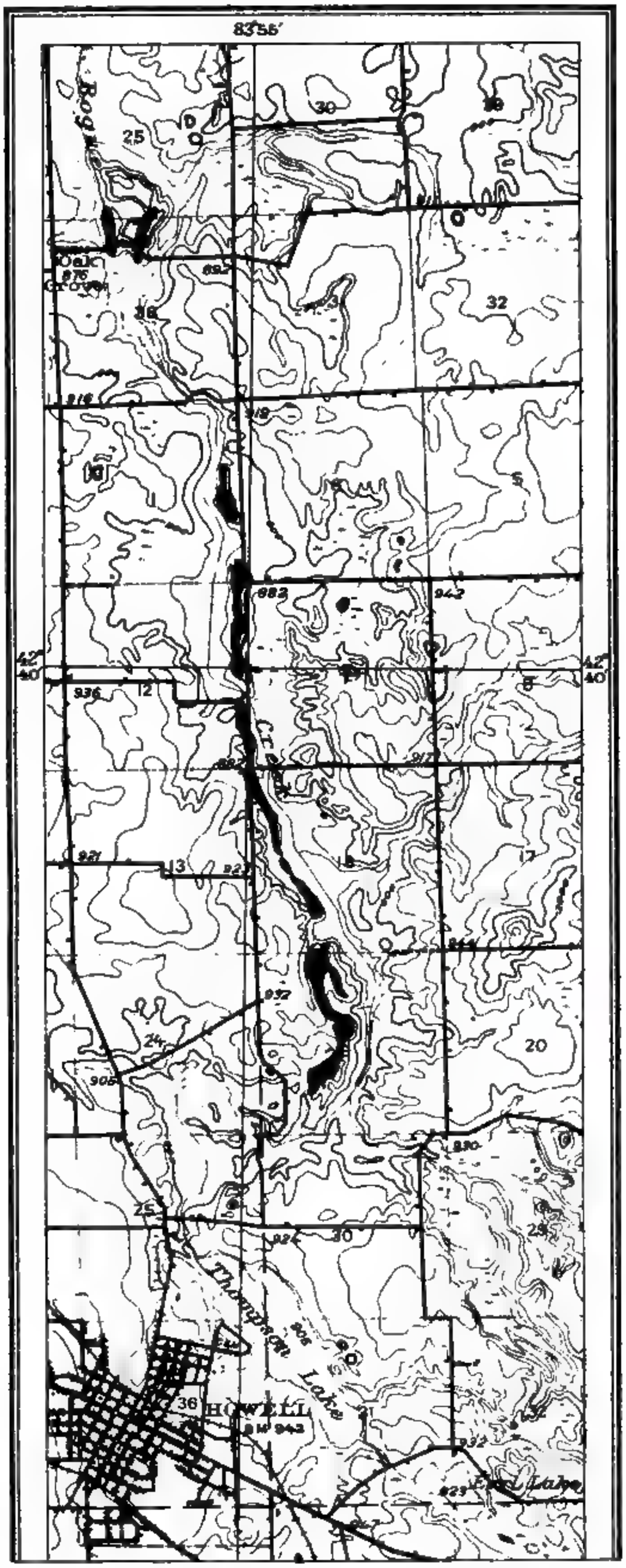
In the valley of North Ore Creek, in the vicinity of Hartland, in eastern Livingston County, a chain of short esker ridges leads southeast into the village of Hartland. This village stands on a plexus of esker-like ridges rising 25 to 40 feet above marshes in the valley, and on an esker fan or delta standing about 20 feet above the marshes. About a mile northwest of Hartland, near the center of sec. 8, a plexus of esker ridges rises 30 to 40 feet above the bordering marshes. The esker is developed in fragmentary form as far north as Parshallville, about 3 miles from Hartland. East of the esker lies a very prominent moraine and west of it a gently undulating till plain. Hartland stands at the southeast edge of the till plain in a recess in the moraine. The swampy depression, which continues from Hartland southeastward through the moraine, is probably a line of subglacial drainage.

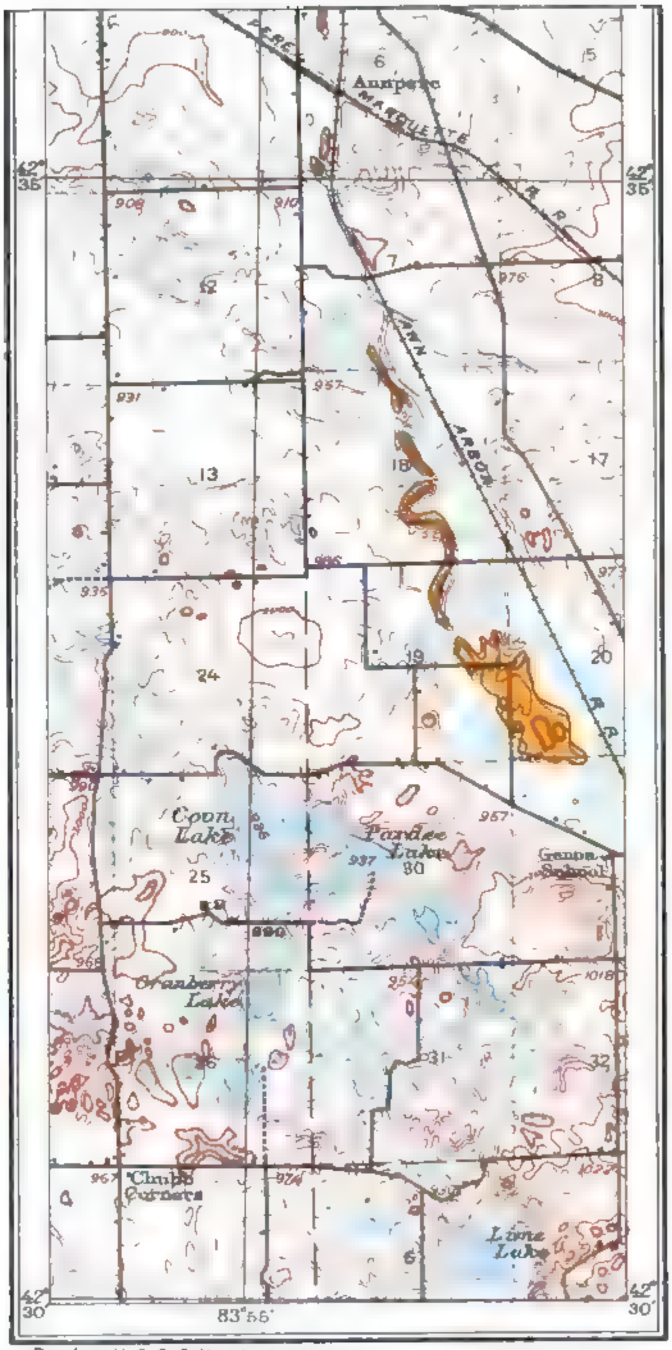
PSEUDO-ESKERS.

In structure the eskers are commonly gravelly with thin beds or small inclusions of sand. Little till is present, though it occurs on a few of the slopes and partly caps some of the short esker-like ridges, as in secs. 30 and 31, Roxana Township, Eaton County. Some ridges have the form of eskers but are composed largely of till; thus, in secs. 24 and 25, Kalamo Township, Eaton County, there are winding ridges of esker type 20 to 30 feet in height and 100 yards or less in width, which have swampy depressions on each side as in the ordinary eskers, but which at an exposure where crossed by an east-west road show till to a depth of 10 to 15 feet. The tops of the ridges are about on a level with the bordering till plain, so that it is possible that they owe their origin to the erosion of the drift in the depressions along their sides rather than to building up by subglacial streams. Or it is possible that the entire topography, depressions as well as ridges, originated without the aid of subglacial drainage, and that the similarity to an esker is a mere accident. Such ridges were noted also in Delhi Township, Ingham County, one group being in secs. 29, 30, and 31 and another in secs. 34 and 35. The first group trends north-northeast and south-southwest and the second group northwest and southeast. The ridges are 15 to 20 feet high and as narrow as the ordinary esker and are bordered on each side by swampy depressions. Ridges of this class may perhaps be termed "pseudo-eskers" until their origin or relation to eskers is determined.

VALPARAISO MORAINIC SYSTEM OF THE LAKE MICHIGAN LOBE.

The Valparaiso morainic system, named from the city of Valparaiso, Ind., was described in Monograph XXXVIII from the Wisconsin-Illinois line around the southern end of Lake Michigan through northern Indiana and northward as far as Allegan County, Mich. The studies on which that description is based were made in 1887 and only a part of the region has been visited by the writer since that year. Studies, however, have been made northward on the east side of Lake Michigan far enough to determine the full extent and relations of the system in that district. These later studies, as indicated in the discussion of the Kalamazoo





Base from U. S. G. S. Howell atlas sheet

Scale

1 0 1 Mile

Contour interval 20 feet.

Datum is mean sea level.

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MAP SHOWING ESKERS NEAR HOWELL, MICHIGAN

morainic system, have led to some changes in the interpretation of the relations of the Valparaiso system to the Kalamazoo.

The present discussion is confined to the portion of the Valparaiso morainic system in Indiana and Michigan, there being no apparent necessity for revising the discussion of the Illinois portion in Monograph XXXVIII. The term "system" is used because the moraine consists in places of two or more constituent ridges. As these ridges interlock at short intervals they scarcely admit of separate discussion and scarcely merit individual names.

COURSE AND DISTRIBUTION.

The Valparaiso morainic system occupies and constitutes the high divide at the head of Lake Michigan, which separates the St. Lawrence from the Mississippi drainage. Its inner border is only 5 to 15 miles from the shore of the lake. Its width, including the small till plains between its constituent ridges, ranges from 5 to 20 miles, and its general width is 7 or 8 miles. It is one of the strongest morainic systems of the Lake Michigan ice lobe. The glacial maps (Pls. VI and VII, in pocket) show its variations in breadth and complexity, and it is here necessary to mention only a few details of its distribution.

In the vicinity of the State line of Illinois and Indiana there are at least three ridges in the system with well-defined crests, but they are so lapped upon one another that no intermorainic spaces occur. In passing eastward to the vicinity of Valparaiso the outer ridge dies out or becomes submerged in the great gravel plain south of the Valparaiso system. The middle and inner ridges are less distinct from Valparaiso eastward than toward the west, and in one place they merge in a single great ridge about 5 miles in width. They are blended or closely associated in Michigan as far northeast as St. Joseph River. East of St. Joseph River they form two prominent moraines separated by a narrow till plain, but farther east, near the line of Berrien and Van Buren counties, they coalesce into a single great belt which runs northeastward across Van Buren County to the Kalamazoo Valley in southern Allegan County. Outside of this great belt are the Kendall moraine and the weak ridges in eastern Van Buren and northwestern Kalamazoo counties (see p. 183) that seem to connect the Valparaiso with the Kalamazoo system. North of the Kalamazoo Valley two prominent moraines appear and continue separate to the southwestern part of Kent County, where the outer merges with the outer ridge of the Charlotte system of the Saginaw lobe; the inner, however, extends nearly to the outer ridge of the Lake Border morainic system. In western Kent and eastern Ottawa counties the association with the outer part of the Lake Border morainic system is so close that some difficulty is found in drawing a continuous line of separation; this, however, may follow a narrow depression that runs southwestward from Grand River to Jamestown and thence southward along Bear Creek to Rabbit River. North of Grand River the Valparaiso system probably includes a strong moraine that lies immediately west of Grand Rapids and extends northeastward into the bend of Rapid River near Rockford, where it connects with the correlative moraine of the Saginaw lobe. It may also include the strong moraine in northwestern Kent and southeastern Newaygo counties that correlates with the inner part of the Charlotte system, and may also include the west part of the interlobate tract in Mecosta and Osceola counties, though this, with the moraines bordering it on the west, may possibly be within the limits of the Lake Border system.

TOPOGRAPHY.

ALTITUDE.

Most of the inner border of the Valparaiso morainic system is between 75 and 100 feet above the level of Lake Michigan, or 655 to 680 feet above sea level, and has but little range in altitude. From it the surface rises at least 100 feet and in places 200 feet or more to the main crest of the morainic system. In Indiana the altitude of the crest ranges from about 750 feet in Lake County to nearly 900 feet in Laporte County, and in Michigan from 750 to 800 feet near St. Joseph River and northward across Van Buren County. The outlying Kendall moraine (p. 183) reaches an altitude of about 900 feet in the northeast township of Van Buren County.

In Allegan County the range is from about 700 feet up to 900 feet. In southwestern Kent County Dias Hill, standing at the point where the moraines of the Saginaw and Lake Michigan lobes come together, reaches an altitude of 1,032 feet and towers more than 100 feet above the neighboring moraine.

Along the outer border the altitude is generally much greater than on the inner border. The difference, however, is slight in the vicinity of the Illinois and Indiana line, where the altitude of the outer border is scarcely 700 feet. The altitude on this border reaches about 800 feet in the vicinity of Laporte, and is maintained eastward to St. Joseph County, Ind. It appears probable, however, that the portion from Laporte eastward (see p. 184) embraces an outwash apron of the Kalamazoo system, for lines of glacial drainage heading in the Valparaiso system are only 775 to 780 feet at their heads. The altitude is below 800 feet in the vicinity of the St. Joseph Valley, but is slightly above 800 in the interval between St. Joseph and Paw Paw rivers. It drops to 750 feet or less at Paw Paw River and remains below 800 feet from there to Kalamazoo River along the border of the Kendall moraine. Between the Kendall moraine and the main moraine to the west, however, an outwash apron stands at an altitude of about 800 feet. From the Kalamazoo Valley northward the outer border is generally slightly above 800 feet.

RELIEF.

The relief on the outer border is thus comparatively slight, being in few places more than 50 to 75 feet and in some places altogether lacking, the moraine scarcely rising to the level of the outwash apron. The relief on the inner border, however, is everywhere conspicuous, ranging from about 100 to 200 feet or more.

CHARACTER.

The morainic system presents great variations in topography, some portions being of a subdued swell and sag type with differences of only 10 to 30 feet between the swells and sags, and other portions being characterized by very sharp knobs among which are deep basins occupied by small lakes. The smoothest portion is found in the vicinity of the Illinois-Indiana line.

As already indicated, three ridges, closely associated and yet having distinct crests, form the morainic system in the vicinity of the Illinois-Indiana line. The northernmost is sufficiently prominent to constitute the divide between the Lake Michigan and the Kankakee River drainage, and yet on the whole is less conspicuous than the middle ridge; the southernmost is the least conspicuous of the three. The interruptions in the middle ridge are very slight, but those in the southern ridge are wide. The only conspicuous lake is Cedar Lake, which is situated about 6 miles southwest of Crown Point, at the head of a valley which leads southward into the Kankakee Marsh. It has an area of 1.17 square miles but is only 18 feet deep.[1]

To the east, in Porter and Laporte counties, Ind., the knolls are sharper and the moraine has great prominence on its inner border, rising in places 150 feet in less than 2 miles. Small lakes are numerous among the morainic knolls and in basins on the gravel plain just outside. From the Indiana-Michigan line northward the contours are commonly sharp, the knolls ranging from 15 to 60 and even to 80 feet in height. Several elevated tracts a few square miles in area rise above the general level of neighboring portions of the moraine; notable are those in Bainbridge Township, Berrien County; in central Lawrence, southern Arlington, and northern Bloomingdale townships, Van Buren County; in northwestern Trowbridge and northern Cheshire townships, Allegan County; and in a tract north of Allegan. Most of these have abrupt borders on two or more sides and a relief of 60 to 100 feet. The tract north of Allegan has an abrupt descent both on the north and the east, and that in Cheshire Township has the same on the north and the west. The tract in Arlington Township, with armlike projections into Hartford Township, has an abrupt border on all sides with a relief of 50 feet or more. The tract in Bainbridge Township has an abrupt border on the north and west and on portions of the east and south. Aside from the greater altitude, these tracts differ but little from the

[1] Determined by the members of the zoological department of the State University of Indiana.

neighboring lower portions of the morainic system, for the latter bear usually sharp knolls and ridges.

Among the places where knobs rise 60 to 80 feet above border portions of the moraine may be mentioned Watson Township, Allegan County; the vicinity of Great Bear Lake in Van Buren County; a strip on the south side of Paw Paw River from near Lawrence nearly to Paw Paw, and several places along the eastern border of the morainic system in Berrien and Van Buren counties.

Swamps are very common among the morainic knolls in the Michigan portion, there being usually several in each township. Most of the lakes are small, few exceeding a square mile in area, though if the bordering swamps are included some of them cover 2 or 3 square miles. Lakes are especially conspicuous along the eastern border of the morainic system and in neighboring parts of its outwash gravel plain.

From northern Allegan County northward to Grand River the morainic tracts are traversed by lines of glacial drainage that break their continuity. The morainic system is also completely cut through by Rabbit River, a tributary of the Kalamazoo heading in northeastern Allegan County. The larger streams, Kalamazoo, Paw Paw, and St. Joseph rivers, all cut through the morainic system and each is bordered by broader terraces and has a valley wider than seems likely to have been produced by the postglacial drainage. The Kalamazoo, however, makes its passage in a rather narrow valley. The several valleys seem to have been utilized as lines of glacial drainage.[1]

STRUCTURE OF THE DRIFT.

THICKNESS.

Along the entire course of the Valparaiso morainic system in Indiana and Michigan the drift is very thick, probably averaging more than 200 feet, and few wells have reached the rock. The greatest thickness reported is at Laporte, where 295 feet of drift was found. Rock surface is in places only about 400 feet above sea level, and nowhere seems to reach 700 feet; it is known to rise above 600 feet only in northern Allegan County and in neighboring parts of Kent and Ottawa counties.

A considerable portion of the drift is probably of pre-Wisconsin age, but the records obtained do not afford as a rule criteria for separating the earlier from the later deposits. The thickness of the Wisconsin drift probably does not greatly exceed the measure of the outer border relief of the moraine except in places where the gravel filling on that border has been great. The gravel filling is of little consequence in northeastern Illinois and in Lake and Porter counties, Ind., but farther east and north it is of considerable depth. The relief in Illinois is estimated to average about 65 feet. The average thickness of the Wisconsin drift may be somewhat less than the relief since the moraine is lower and the drift probably thinner on the borders than along the main crest. In all probability the thickness of the Wisconsin drift is as great along the portion of this morainic system in southwestern Michigan as in northeastern Illinois.[2]

COMPOSITION.

The drift shows interesting changes in structure along the course of the Valparaiso morainic system from Illinois into Indiana and Michigan. In Illinois the Wisconsin drift is mainly a blue clayey till similar to that forming a considerable part of the Wisconsin drift in Wisconsin. Eastward into Indiana till continues to predominate over sand and gravel only about to the meridian of Valparaiso, beyond which to the northeast sand and gravel greatly predominate over the till. The prominent portions of the morainic system appear to contain a larger proportion of sand and gravel than the lower areas, not only in Porter and Laporte counties, Ind., but also in Michigan; wells that penetrate nothing but sand and gravel for 100 feet or more are not

[1] For a detailed description of the portion of this morainic system in Allegan, Van Buren, and Berrien counties, Mich., see Mon. U. S. Geol. Survey, vol. 38, 1899, pp. 348-353.

[2] A list of 68 borings along the Valparaiso morainic system in northeastern Illinois, northwestern Indiana, and southwestern Michigan is presented in Mon. U. S. Geol. Survey, vol. 38, 1899, pp. 354-355.

uncommon, though most of them contain a little till. The marked differences are probably referable in part to drainage conditions attending the deposition of the drift and in part to original sandiness of the material embedded in the ice. Mr. Taylor[1] has called attention to the fact that the gravelly and sandy portion of the morainic system coincides in extent with the belt of prominent dunes along the shore of Lake Michigan and has suggested that the great abundance of sand in this portion of the moraine may be due to its blowing in from lake dunes during an interglacial interval. Probably, however, the principal factor has been the glacial drainage, which was exceptionally vigorous in the region. Furthermore, the sandy and gravelly character of the drift extends eastward over several counties in southern Michigan beyond the reach of the Lake Michigan dunes.

Well records setting forth the structure of the drift along this morainic system have already appeared in other publications.[2]

BOWLDERS.

Bowlders in moderate number strew the surface of the moraine, but are on the whole less abundant than in the Kalamazoo morainic system. The great majority are crystalline rocks of Canadian derivation 3 feet or less in diameter. A few immense bowlders of limestone and sandstone were noted in western Van Buren County.

In western Bangor Township sandstone bowlders are scattered over a tract about 1½ miles from north to south and scarcely one-half mile in width, but are most abundant in secs. 16 and 17, and especially on a prominent knoll on the section line. One bowlder on this knoll supplied stone to build a large house in Hartford. Two others still remain, one measuring 24 by 21 by 21 feet on the sides, and the other 30 by 18 by 15 feet; each stands 6 or 8 feet above the surface and extends to an undetermined depth—one of them to at least 6 feet. Similar bowlders are scattered over Bloomingdale Township, in a belt nearly 3 miles in length and about one-fourth mile in width, extending from near the base line in sec. 4 south into sec. 17, about half a mile west of Bloomingdale station. They appear on the most prominent points along this line, but are scarce on the lowland between the knolls. They are embedded in the ground at various angles, some standing nearly on edge. The largest measure 15 to 20 feet and stand 6 to 8 feet above the surface. Similar large sandstone bowlders are reported from sec. 33, Bloomingdale Township, but were not visited by the writer. These sandstones are mainly red or pink or more rarely brown. They have some of the characteristics of the Potsdam sandstone, but their geologic horizon has not yet been fully settled.

A large limestone block in sec. 11, Hartford Township, had been uncovered at the time of the writer's visit over about 16 feet square and had been quarried to a depth of about 3 feet, yet neither its lateral limits nor its bottom had been reached. A bowlder of the same kind of limestone occurs on the base line between Bloomingdale and Cheshire townships less than a mile west of the north end of the sandstone bowlder belt above noted. It, however, is only about 5 feet cube. A large limestone bowlder in Van Buren County was examined by Alexander Winchell and was referred by him to the "Corniferous." Winchell supposed the bowlder to have been transported from the western end of Lake Erie, but the Erie ice movement can scarcely have extended to Van Buren County. It is more probable that it was derived from ledges to the north of Van Buren County.

OUTWASH.

The drift is gravelly or sandy all along the outer border of the Valparaiso morainic system from its junction with the correlative moraine of the Saginaw lobe in southern Kent County, Mich., southward to the edge of the Kankakee Marsh in Porter County, Ind. Characteristic pitted plains, forming outwash aprons along a considerable part of the border, slope rapidly away toward the lower land along the inner border of the Kalamazoo morainic system. It is

[1] Personal communication.

[2] For wells in Illinois and southwestern Michigan see Mon. U. S. Geol. Survey, vol. 38; for wells in northern Indiana see Water-Supply Paper U. S. Geol. Survey No. 21; for records of flowing wells in the lowlands among the morainic knolls and ridges of this system see Water-Supply Paper U. S. Geol. Survey No. 182.

probable that the water after running across these outwash aprons formed long pools on the inner border of the Kalamazoo system connected by short, slightly channeled stretches, where the stream descended from one pool to another. In Indiana the drainage from the Valparaiso system seems to have been confined to broad, shallow valleys that lead across the high gravel plain (p. 180).

DRAINAGE.

The drainage of the Valparaiso system can perhaps best be outlined from south to north, for the most southerly channels probably came into operation somewhat earlier than the more northerly.

From the meridian of Valparaiso westward streams which head as far back as the middle and even as the northernmost of the three ridges of that part of the system wind about through small valleys in which there is but little filling by deposits of gravel and sand connected with the retreat of the ice. This portion of the moraine, as already indicated, is clayey in constitution and seems to have had a very weak outwash. The first stream east of Valparaiso, Crooked Creek, occupies one of the broad shallow valleys that leads across the large gravel plain of the upper Kankakee region. Between this valley and Laporte other streams lead across the gravel plain, but they are in small narrow valleys which evidently were not utilized to any great degree by drainage from the Valparaiso system. Little Kankakee River, which heads near the outer border of the Valparaiso system about 5 miles northeast of Laporte, is in a broad shallow valley that apparently received a line of drainage from the Valparaiso system; its bottom lands are covered with a rather fine sandy gravel not so coarse as that forming the bordering gravel plain and suggesting a rather weak drainage. Immediately east of New Carlisle a low plain of sandy gravel, known as Terre Coupee Prairie, heads in the Valparaiso system and leads southward to the Kankakee; its material is decidedly finer than that on the higher gravel plain to the west and thus suggests comparatively weak drainage. From Terre Coupee Prairie a narrow strip of sandy gravel extends northward to the bend of St. Joseph River at Buchanan and separates the Valparaiso system from the inner moraine of the Kalamazoo system. This strip is lower than the outwash apron on the eastern side of the inner moraine of the Kalamazoo system, and in places the stream that followed it has cut into the latter.

In the district between St. Joseph and Paw Paw rivers the Valparaiso system is bordered by an extensive gravel plain thickly set with basins near the edge of the moraine and sloping rapidly southeastward toward Dowagiac River. Its altitude is somewhat above 800 feet at the edge of the morainic system, but is only 760 to 775 feet in the vicinity of Dowagiac River. It is probable that at the time the weak ridge running from Paw Paw northeastward to the Kalamazoo system was occupied by the ice sheet the head of glacial drainage was immediately east of Paw Paw. The waters appear to have followed the swampy channel that leads from Paw Paw to the headwaters of the Dowagiac (see p. 184) and to have entered, near Dowagiac, at an altitude of about 720 feet, Lake Dowagiac, which extended as far south as South Bend, Ind., where it opened into the head of the Kankakee. This pool appears to have been a few feet lower than the line of glacial drainage from the bend of the Kalamazoo at Buchanan to Terre Coupee Prairie and was probably in the line of main discharge from the ice border between Buchanan and Paw Paw during the development of the extensive outwash apron.

Though the portion of the ice border between Paw Paw and Kalamazoo River east of the Kendall moraine and of its apparent weak correlative in northwestern Kalamazoo County has not so high an outwash apron as the portion between Paw Paw and Buchanan, yet it has along much of its length a narrow pitted plain standing a little below 750 feet at the southern end of the Kendall moraine and about 775 feet at the place where the weak moraine of northwestern Kalamazoo County joins the inner moraine of the Kalamazoo system. The district contains a swampy tract whose altitude is about 30 feet lower than that of the gravel plain; but this, as already indicated, was probably opened by a line of glacial drainage that discharged down the Paw Paw Valley instead of southward to the Kankakee. The outwash apron seems

to be barely high enough to have been connected with the drainage to the Kankakee, for the swamp which leads southward from Paw Paw to Dowagiac is only about 750 feet in its highest part and has been filled to some extent by peaty accumulations.

If, as seems probable, the ice at the time the Kendall moraine was forming extended to the edge of the Kalamazoo system from Kalamazoo River northward, its drainage in the district north of the Kalamazoo is likely to have been in the same direction as it was during the development of the Kalamazoo system or southward past the site of the city of Kalamazoo to St. Joseph River.

As the ice shrank back from the inner border of the Kalamazoo system in the district north of Kalamazoo River it formed an extensive gravel plain thickly set with basins. This plain slopes eastward in the region west of Gun Lake and Gun River, but farther north in the reentrant angle between the moraines of the Saginaw and Lake Michigan lobes it slopes southward. Gravel appears at two distinct levels, a part of the outwash apron having been cut away to a depth of 30 or 40 feet by glacial drainage and a part remaining at the original level of filling. This lower plain has one arm extending northwestward from Gun Lake to a strong ridge of the Valparaiso system near Wayland and another arm extending northeastward to the moraine of the Saginaw lobe at Middleville. From the junction of these two arms the drainage is southward along the Gun River marsh to the Kalamazoo and thence along the marsh which connected the Kalamazoo with the Paw Paw along the eastern side of the Kendall moraine. The features suggest that at the time this lower plain was being developed the ice had withdrawn sufficiently from the lower course of Paw Paw River to permit drainage down its valley to the vicinity of Benton Harbor. At the time the higher or main outwash apron was being developed the drainage seems likely to have been southward to South Bend along the lines followed by the portions of the glacial drainage south of the Kalamazoo.

When the reentrant between the Lake Michigan and Saginaw lobes stood just north of Grand Rapids an outwash apron was developed in front of the Saginaw lobe on the east side of Grand River at an altitude of about 700 feet. An outwash apron along the front of the Lake Michigan lobe, south of Grand Rapids, in Wyoming and Byron townships, Kent County, has a similar altitude, being just below 700 feet, as shown by the Grand Rapids topographic sheet. The water evidently found escape southward between the two lobes past Grand Rapids, Carlisle, and Ross to Rabbit River near Dorr. The course beyond Dorr is less easy to interpret. Two courses are possible, and their relation to the drainage southward from Grand Rapids depends on the amount of recession that had been made by the Lake Michigan lobe at that time. If the ice still covered the strong moraine north of the city of Allegan and also the moraine southwest of that city the drainage is likely to have followed the line of a swampy depression utilized by the Lake Shore & Michigan Southern Railway from Dorr to Allegan, and then to have passed up the Kalamazoo Valley from Allegan to Otsego and turned southward into the Paw Paw drainage; to have taken this course, however, the waters must have passed over divides that rise a few feet above the 700-foot contour, or higher than the source of the glacial drainage near Grand Rapids. If, on the other hand, the ice had withdrawn from the prominent morainic tracts near Allegan the glacial drainage may have passed southwestward between the ice border and these moraines into a local lake in the lower part of the Kalamazoo Valley. The drainage from Dorr into this lake came eventually if not at the beginning of the drainage southward from Grand Rapids. The indefiniteness of the correlations in different parts of the Valparaiso morainic system renders questions of this sort perplexing, and the full solution must depend upon the fuller correlations along the lines of the several members of the system.

The drainage from the reentrant between the Lake Michigan and Saginaw lobes in southeastern Newaygo, southwestern Mecosta, and western Montcalm counties is likely to have passed southward through the valley of Rapid River to its junction with the Grand River near Grand Rapids, and possibly it continued southward to Dorr along the line just discussed into Rabbit River. An outwash apron, developed on the east border of the Lake Michigan lobe in

the southeast part of Newaygo County, slopes rapidly eastward away from the moraine. A few miles farther north, in the southwest corner of Mecosta County, an outwash apron of the Saginaw lobe slopes southwestward from the moraine in the district between Muskegon and Little Muskegon rivers. Whether the drainage from this northern outwash apron was southward through the western edge of Montcalm County or whether it followed down the Muskegon past the mouth of the Little Muskegon and then went southward past Rice Lake into the Rapid River valley depends on the amount of recession that had been made by the Lake Michigan lobe in southeastern Newaygo County.

CHAPTER X.

LATER MORAINES OF THE LAKE MICHIGAN, SAGINAW, AND HURON-ERIE LOBES.

LAKE BORDER MORAINIC SYSTEM OF LAKE MICHIGAN LOBE.

By Frank Leverett.

COURSE AND DISTRIBUTION.

A complex group of moraines closely bordering the southern end of Lake Michigan was discussed in Monograph XXXVIII under the name Lake Border morainic system. This system has now been traced northward along the eastern side of the Lake Michigan basin, across the highlands between the northern part of Lake Michigan and Saginaw Bay, around the circuit of the Saginaw Basin to the "thumb" of Michigan, and southward through southeastern Michigan along the eastern slope of the "thumb." In places, however, it is so intricately combined with earlier and later systems that its differentiation is not complete. The individual moraines of this system are still more difficult to trace around this entire circuit, for in some places they are bunched together and in others they are interrupted by gaps of considerable width.

Only in the southern part of the Lake Michigan basin is the Lake Border the innermost system; in the northern part later moraines which do not extend so far to the south lie within it. As far north as Holland the Lake Border system lies close to the shore of Lake Michigan, but from Holland northward to Oceana County it is 15 to 25 miles back from the shore. In Oceana County it returns to the shore and forms the prominent "clay banks" in the southwestern part of the county. From the vicinity of Hart northward it bears inland and is shut off from the lake by later moraines. It wraps around the northern part of the great interlobate moraine between the Lake Michigan and Saginaw lobes (see Pl. VII) and a little north of Cadillac bears away eastward. Within a short distance its southern or outer members turn southeast into the Saginaw basin, but its later members make longer circuits and run nearly to Lake Huron before doubling to the south. In Newaygo and Lake counties the Lake Border system banks against the earlier interlobate moraine to the east, but in Wexford and Missaukee counties it is quite distinct from the interlobate, and it remains so in its course southward along the west side of the Saginaw basin.

TOPOGRAPHY.

ALTITUDE.

The outer members of the Lake Border morainic system reach their greatest height immediately north and west of Cadillac, where they attain an altitude of 1,500 feet above sea level. The outermost ridge for 20 miles west from the line of Missaukee and Wexford counties stands above 1,400 feet. Beyond the turn to the south the ridge gradually declines in altitude, but a considerable portion of it is above 1,100 feet as far south as the latitude of Big Rapids and some points on it are above 1,300 feet as far south as the latitude of Baldwin. The ridges south of Muskegon River are scarcely 800 feet in altitude, the descent being very rapid from the great morainic mass north of Muskegon River to the slender moraines that lead away to the south. The decline becomes more gradual as the head of Lake Michigan is approached, but from the vicinity of South Haven southward to the head of the lake the ridges stand less than 700 feet above sea level.

In the great morainic mass which protrudes westward across Oceana County points within a few miles of the shore of Lake Michigan stand as high as 1,000 feet and large areas stand above 800 feet, or more than 200 feet above Lake Michigan.

The inner part of the morainic system is highest at the north a few miles south of Gaylord, where it touches the 1,400-foot contour. It declines steadily southwestward and keeps above the 1,300-foot contour to about the line of Antrim and Kalkaska counties, above the 1,200 to about the latitude of Kalkaska, and above the 1,100 to the line of Kalkaska and Grand Traverse counties. A few points in southern Grand Traverse County and on the moraine as far southwest as the bend of the Manistee in eastern Manistee County reach 1,000 feet. South of Manistee River most of the ridges on the inner border of this great system fall below 800 feet and part of the surface below 700 feet.

RELIEF.

On the outer border of the system in the vicinity of Cadillac the ridges have a relief of 50 to 100 feet or more above an outwash plain which covers much of southeastern Wexford County. The inner border relief of this portion of the system is 300 to 400 feet in Wexford County and about 300 feet in eastern Lake and northeastern Newaygo counties. The great morainic mass which runs westward from Newaygo County across Oceana County has a relief of 150 to 300 feet or more above the plains on its north and south borders. The slender moraines running southward from Muskegon River have a relief generally less than 100 feet, dropping to scarcely 50 feet as they near the head of the Lake Michigan basin; the inner or western moraines have generally considerable relief, but the outer ones rise very little above the eastern outwash plains.

CHARACTER.

The Lake Border morainic system has an exceptionally great variety of topographic expression, for it comprises the great ridges formed by convergence of ice movement and concentration of material at the north end of the peninsula, as well as the weak ridges formed where the ice was more free to spread out at the south end of the Lake Michigan basin. The rugged northern portion not only shows great relief, but parts of it north of Muskegon River have been cut by glacial drainage into an intricate network of prominent ridges and broad gravelly flats. The outer part, however, in eastern Newaygo and Lake counties and southeastern Wexford County is almost unbroken by drainage gaps.

The ridges north of Muskegon River present a billowy surface with knolls 50 or even 100 feet in height, inclosing sags and basins. The ridges, which tend to parallel the trend of the morainic belt, become successively lower toward the inner or western part of the system.

The great morainic spur in Oceana and western Newaygo counties has a very billowy surface and great irregularity in height independent of the numerous gaps made by glacial drainage in the eastern part. The ice border seems to have shrunk across this morainic spur from east to west, and during the recession its escaping waters eroded the eastern part.

In the district between White and Muskegon rivers evidence is preserved of the recession of the ice border to the south of west. A billowy moraine leading southeastward from Hesperia to Newaygo has an outwash apron on the northeast and a till plain on the southwest. In Muskegon County this till plain includes a pitted gravel plain which is in places bowldery and seems to mark a receding ice border.

South from Muskegon River till ridges interrupted here and there by gaps in which sand plains occur, bearing low swells and shallow basins on their gentle slopes, extend all the way to the head of Lake Michigan. The basins and low plains were covered by the waters of Lake Chicago after the ice had disappeared.

STRUCTURE OF THE DRIFT.

THICKNESS.

On the borders of Lake Michigan the drift extends considerably below lake level, except in a few places such as the Waverly district near Holland and the New Troy district in Berrien County, where rock is reached a little above lake level. At Ludington and Manistee the drift extends below sea level, about 640 feet being present in some of the borings for salt on the low plain at these cities. Bedrock surface is only 300 to 400 feet above sea level along much of the eastern shore of Lake Michigan between Grand Haven and Grand Traverse Bay, and is generally less than 500 feet above in the district south of Grand Haven, as may be seen by reference to the map of rock contours (Pl. II). The altitude of the rock surface inland from the lake is known at very few places, but it probably nowhere much exceeds 800 feet above sea level in the northern end of the southern peninsula. Its maximum height may be attained in the northern part near Gaylord, but it is very doubtful if it is held beneath the highest part of the morainic system in Wexford, Lake, and Newaygo counties; more probably the rock there is as low as the level of Lake Michigan. Such being the case, the drift on these high ridges is 700 to 1,000 feet or more in thickness and it probably averages over 500 feet from the vicinity of Gaylord to Newaygo. From Newaygo to the head of the lake the average thickness is probably not far from 200 feet, the altitude of this district being comparatively low and the rock surface somewhat higher than in the district to the north.

The drift is probably in large part pre-Wisconsin in age, but data are not numerous that bear upon the separation between the Wisconsin and pre-Wisconsin deposits. Records of flowing wells in the district about 4 miles southwest of Shelby in Oceana County indicate the presence of peat or black muck at a depth of 175 to 200 feet (75 to 100 feet below the surface of Lake Michigan), and this seems likely to mark the separation between the Wisconsin and pre-Wisconsin drift. The wells were continued only to the bed of sand or gravel which immediately underlies the black muck. One well penetrated 15 feet of muck and two others nearly as much. The older drift beneath the muck is likely to be fully as thick as the younger drift above, for a well at Shelby, 4 miles away, on ground only about 100 feet higher than at these wells, penetrated 500 feet of drift.

COMPOSITION.

Along the entire length of the rugged portion of the Lake Border morainic system wells ordinarily pass through a large amount of loose-textured sandy or gravelly drift. In places this material is thinly capped with till but is thickly set with bowlders; in many other places it is sandy from the soil down to the bottom of the wells, most of which require curbing while in process of excavation. Bowlders are conspicuous on the prominent ridges from Oceana County northward. Large limestone blocks also occur; some of these in Oceana County were burned for lime in the early days of settlement, and led to the incorrect inference that limestone ledges are present in that county. Wells, however, indicate that the rock surface lies nearly 300 feet below the surface of Lake Michigan. Calcareous material, which is found in considerable abundance in the loose-textured drift deposits of the region, as noted many years ago by R. C. Kedzie while analyzing soils from that part of the State,[1] gives the soil great fertility.

From Muskegon River southward to the head of Lake Michigan the ridges of this morainic system are composed largely of grayish-blue clayey till. In some places the till contains only a few small pebbles, and in others it is laminated, indicating that it was water-laid. The crests of the ridges, however, seem to be land laid. Exposures of the laminated material may be seen here and there along the bluffs of Lake Michigan from Kalamazoo River southward.

Bowlders are found in moderate number along these till ridges but are less numerous than on the rugged portion of the morainic system farther north. They are chiefly of granite, though other kinds of rock are present. Large bowlders of reddish sandstone, similar to those on the

[1] Ann. Repts. Michigan Board of Agriculture for 1878, 1887, 1888, and 1893.

Valparaiso morainic system near Bloomingdale and near Bangor, were noted on the crest of one of these till ridges in western Allegan County.

The plains bordering the moraines show the same changes as the moraines in passing from north to south, those in the northern portion where the ridges are sandy and gravelly being underlain by sandy material, and those in the southern portion bordering the till ridges being underlain by clayey material. In a few places, as between Muskegon and Grand rivers, a thin outwash of sandy gravel, derived from the ice border during the development of the till ridges covers the till.[1]

GLACIAL DRAINAGE.

LINES OF DISCHARGE.

Reference has already been made (p. 223) to the numerous lines of glacial drainage developed in connection with the recession of the ice border from the outer to the inner members of the Lake Border morainic system. In most areas the lines of discharge for the glacial waters are very clearly shown. The most elevated outwash tract is found just north and west of Cadillac, where about 100 square miles, standing at an altitude of 1,300 to 1,350 feet, was coated with sand and gravel by streams issuing from the outer moraine. Clam River, a tributary of Muskegon River, heads in this plain and, with the Muskegon, probably carried the glacial waters to just above Newaygo, where they were deflected by ice to a well-defined channel that leads southward past Rice Lake to Rapid River, a tributary of Grand River. From Grand River near Grand Rapids the glacial waters made their way southward along the edge of the ice through narrow lakes to the incipient Lake Chicago at the head of the Lake Michigan basin and thence down the Chicago outlet.

As a rule the outwash in all the lines of glacial drainage connected with the Lake Border system is a rather fine sandy material.

GLACIAL LAKES.

Distribution.—During much of the time when the Lake Border morainic system was forming the area now covered by Lake Michigan was occupied by ice, and the drainage of western Michigan was forced to follow the eastern edge of the ice sheet southward to the southern end of the basin, where it found discharge through the Chicago outlet into the Desplaines Valley and thence to the Illinois and Mississippi valleys and the Gulf of Mexico. At that time the eastern tributaries, which now lead through the Lake Border morainic system directly to Lake Michigan, seem to have flowed south through a series of small glacial lakes that occupied the lowest available ground outside the ice sheet. In the early part of the development of the system, while the ice still covered the moraine north of Rabbit River in northern Allegan County, the northernmost lake in the series was apparently one that occupied the lower Kalamazoo Valley and received drainage from districts farther north through rivers whose courses lay outside the edge of the ice sheet. Grand River discharged into this lake along the abandoned channel that runs southward from Grand Rapids past Ross to Rabbit River. In the course of development Muskegon River also found its way to Grand River at Grand Rapids through a valley leading past Rice Lake to Rouge River, a tributary of Grand River heading in southern Newaygo County. Later, when the ice border was close to Lake Michigan near Holland, more or less ponding probably took place on the lower courses of White, Muskegon, and Grand rivers and a nearly continuous lake probably extended along the edge of the Lake Michigan basin from near Holland to the Chicago outlet.

The small lakes along the edge of the ice in southwestern Michigan did not form beaches of sufficient definiteness to permit easy mapping. The levels at which they stood can, however, generally be determined by the deltas of their large affluents and by the height of their outlet channels. The series of lakes and connecting channels was so complicated that the writer did

[1] For further details of the drift structure see Mon. U. S. Geol. Survey, vol. 38, and Water-Supply Papers U. S. Geol. Survey Nos. 21, 182, and 183.

not attempt to map them completely but simply determined the general extent and approximate level of each lake and its probable course of discharge to the next. When topographic maps have been made it will not be difficult to represent these lakes more definitely.

Lake on the lower Kalamazoo.—The glacial lake that occupied the lower Kalamazoo covered much of the space between the Lake Border and Valparaiso morainic systems from Rabbit River southward into the Black River drainage basin in northwestern Van Buren County. Its northern limits were determined by the strong morainic ridge that lies north of Rabbit River in northern Allegan County. Several lines of evidence unite in fixing its altitude at about 680 feet; the sandy plain that now occupies its bed is definitely limited on the east and south by the Valparaiso system at an altitude of very nearly 680 feet, as shown by the railway elevations at Dunning and at Columbia and Grand Junction, and is bordered by a well-defined terrace of the Kalamazoo Valley at about 680 feet; further, the altitude of an outwash apron of the Lake Border morainic system near Fennville is about 680 feet. This lake appears to have at first discharged southward to Paw Paw River past Breedsville and Bangor and through swampy channels near McDonald, coming to the Paw Paw Valley near Hartford; but when the ice had shrunk back to Covert Ridge [1] the lake may have discharged along the eastern edge of the ridge, which is bordered by a somewhat sandy plain. The relative elevations of the two courses of discharge are not known, but they certainly differ by only a few feet.

The pitted gravel plain near Fennville occupies an area of several square miles along the outer border of Covert Ridge. Close to the ridge basins are conspicuous and the gravel is of medium coarseness; a mile or two outside the basins disappear and the gravel gives place to sand. The border of the glacial lake probably lay along the eastern edge of the basins. Small strips of gravel plain, preserved along the south edge of the moraine north of Rabbit River, lie at an altitude high enough to have been deposited outside of or above the edge of the glacial lake. The material is decidedly coarser than that on the sandy plain to the south.

Lake in lower St. Joseph and Paw Paw valleys.—The next lake in the series stands in the lower St. Joseph and Paw Paw valleys in Berrien County. This lake appears to have extended up the Paw Paw Valley about to Hartford and to have there received the drainage of the lake in the Kalamazoo basin. It filled in the narrow space between the Lake Border and Valparaiso systems from near Hartford southward about to Baroda, 10 miles south of St. Joseph, and crossed the divide between the St. Joseph and Galien river systems through a swamp south of Baroda. The altitude of this lake appears to have been about 20 feet lower than that of the lake in the Kalamazoo basin, as determined by the level of the outlet near Baroda and by a terrace on the St. Joseph near Berrien Springs which seems to be correlated with this lake and which stands about 660 feet above sea level. The outlet of this lake cuts into the edge of the part of the Valparaiso system directly east of Baroda and appears also to have cut slightly along the east edge of the outer ridge of the Lake Border morainic system west of Baroda. These cut banks are, by hand level from Baroda, 20 feet higher than the station, or 660 feet. The area occupied by the lake in the Paw Paw and St. Joseph valleys has a coating of gravel and sand several feet in depth, in places overlying a pebbleless silt. Whether the silt is to be correlated with this small lake and the overlying gravel and sand with Lake Chicago which afterward came into the same district can not at present be stated. Probably, however, the streams draining into the larger and longer-lived lake contributed a considerable part of the sand and gravel.

Lake on Galien River.—A pool 1 to 3 miles wide appears to have occupied the lower courses of the tributaries of Galien River in southern Berrien County, extending from the vicinity of New Troy southward about to the State line and covering the western part of the space between the outer ridge of the Lake Border morainic system and the inner edge of the Valparaiso system. The soil in the areas supposed to have been covered by this pool is more sandy than that on a till plain lying nearer the inner border of the Valparaiso morainic system. After the ice had withdrawn from the outer ridge to the second ridge this pool spread into the narrow strip lying

[1] This name was applied in Mon. U. S. Geol. Survey, vol. 38, to the principal till ridge of the Lake Border morainic system.

between the two ridges in southern Berrien County and the neighboring part of Laporte County, Ind., but does not appear to have been markedly lowered.

Lake on Trail Creek.—From the south end of the pool on Galien River the waters passed across a low divide to a pool in the lower course of the two forks of Trail Creek east and south of Michigan City, Ind., and from this pool to Little Calumet River, and thence into a small lake that extended from near Chesterton, Ind., to the Chicago outlet. The drainage from the lake on the St. Joseph descended only 20 feet to the Calumet Valley near Chesterton, and this descent was apparently made in the short passages from one pool to another. Sand is found along much of the course of this drainage but is perhaps in part due to deposition from the receding ice sheet as it melted back from the Valparaiso to the Lake Border morainic system; some of it, however, was probably deposited by this drainage.

Incipient Lake Chicago.—The lake at the south end of the Lake Michigan basin should, perhaps, be termed the incipient Lake Chicago, for it developed into that lake and had the same level and the same outlet. Its level was about 60 feet above Lake Michigan, or 640 feet above tide. As its southern limits are the same as those of the highest or Glenwood stage of Lake Chicago, the description of the border of the Glenwood beach given in Monograph XXXVIII applies to the border of this lake from near Chesterton to the Chicago outlet; the smaller lake, however, probably contributed but a small part of the beach material of this highest stage of Lake Chicago. This small lake expanded northward as the ice receded; in the early days of the Lake Border morainic system it stood entirely outside the limits of Lake Michigan, but by the time the till ridge south of Holland had been formed it probably extended some miles over the bed of the southern end of Lake Michigan. A considerable part of the district occupied by this lake is coated heavily with sand and sandy gravel, much of which seems referable to currents in the later and more expanded lake, but some of which may have been deposited earlier, during the recession of the ice from the Valparaiso to the Lake Border morainic system.

Wisconsin and Illinois drainage.—In southern Wisconsin and northern Illinois the lines of glacial drainage are traceable on the topographic maps from Milwaukee southward to Des Plaines River and to the Chicago outlet. There appears, therefore, to have been no marked ponding of the waters along the ice front on the Wisconsin side of the Lake Michigan basin.

LATE GLACIAL DRAINAGE.

In the later stages of the development of the Lake Border morainic system considerable ponding took place farther north than the Kalamazoo Valley and was apparently maintained until the ice border had receded from the morainic ridges near Holland sufficiently to allow free communication west of them to the somewhat expanded Lake Chicago. During the occupancy and development of the portion of Covert Ridge north of Kalamazoo River, the drainage apparently made its way by streams and small lakes into the glacial lake on the Kalamazoo. But when the ice border had receded to the westernmost of the till ridges in Ottawa County the water apparently found its way along the ice border to the vicinity of Holland and there entered Lake Chicago.

At one time during the recession of the ice border the Muskegon, which received drainage from the Lake Michigan lobe on the west and from the Saginaw Bay lobe on the east, ran southward past Rice Lake in southeastern Newaygo County, its altitude near Rice Lake being about 800 feet above sea level. It followed Rouge River to its junction with Grand River near Grand Rapids and probably continued southward (for a time at least), leaving the Grand River valley at the south edge of Grand Rapids and traversing a valley which leads past Ross to Rabbit River and thence into the lake in the lower part of the Kalamazoo. The altitude of the abandoned valley that runs south from Grand Rapids, as shown by the Grand Rapids topographic sheet, is somewhat less than 700 feet, or fully 100 feet below the channel in Newaygo County, where the Muskegon waters passed Rice Lake into the Grand River drainage. There probably was some ponding of waters along the Rouge Valley, but the valley is comparatively narrow and the ponded water would be considered a river pool rather than a lake.

The discharge from Grand Rapids southward to Rabbit River probably continued until the ice border had withdrawn to the vicinity of Jamestown, when a passage was opened past that village into the lake on the lower Kalamazoo. Aneroid readings indicate that the altitude of the Jamestown channel was very nearly the same as that of the Ross channel, each being apparently between 680 and 700 feet at the present water partings in these channels. The Jamestown channel is very much smaller than the Ross channel, being about one-eighth mile wide, whereas the Ross channel is about one-half mile. It may, therefore, have carried only a portion of the glacial drainage, in which case the Ross channel continued in operation until a lower outlet farther west became available.

A small glacial lake seems to have been present southeast of Holland at an altitude higher than either the Ross or the Jamestown channel. The lake stood between the large morainic ridge north of Rabbit River and the smaller ridge immediately south and east of Holland. The southern shore of the lake is marked by a definite sandy ridge that passes through Fillmore and Overisel along the inner slope of the morainic ridge. Its altitude is about 120 feet above Lake Michigan, or 700 feet above sea level. The sand ridge corresponds pretty closely in altitude to a narrow sag or depression east of Drenth, which leads across the divide between Black River and Bear Creek and which seems likely to have served as an outlet for this small lake into the Bear Creek valley and thence, by a descent of about 20 feet, to the lake on the lower Kalamazoo. The sand ridge on the border of this small lake was mentioned in Monograph XXXVIII as a possible high shore of Lake Chicago, but further studies in that region have led to the abandonment of this interpretation.

North of Grand River in eastern Ottawa County narrow sags between the morainic ridges are filled to some extent by sand and gravel that was probably deposited in part as outwash during the development of the morainic ridges and in part as glacial drainage from districts to the north. The sandy strip east of the eastern of the two till ridges in the region heads in the valley of East Crockery Creek, but leaves that valley near Conklin and passes to the Sand Creek valley, through which it continues to the Grand River valley. Its altitude at Conklin is very nearly 700 feet, or sufficiently high to have thrown the discharge past either Ross or Jamestown, in case no lower passage toward the west was available.

The sag between the two till ridges of northeastern Ottawa County appears to have been utilized by the glacial drainage from West Crockery Creek, the glacial stream having left the Crockery Creek valley near the Muskegon-Ottawa county line. It was probably also utilized by the drainage from a small glacial lake that occupied a sand plain on the borders of the Muskegon Valley, a few miles east of Muskegon, there being a swampy channel just north of Ravenna that afforded a passage from this sandy plain into the Crockery Creek drainage. This swampy channel is at about the level of the flat sandy tracts, or very nearly 690 feet above sea level, as indicated by railway stations at Mooreland and Twin Lakes.

It is probable that an outlet directly into Lake Michigan near Holland had been opened by the time the westernmost till ridge in Ottawa County was formed. The altitude of the waters on the east side of the till ridge would be likely to be governed by the height of the ground (about 680 feet) on the east side of the western till ridge immediately north of Zeeland.

REENTRANT DISTRICT BETWEEN THE SAGINAW AND LAKE MICHIGAN LOBES.

By Frank Leverett.

In the discussion of the Kalamazoo and Valparaiso morainic systems of the Lake Michigan lobe the interlobate moraine between the Lake Michigan and Saginaw lobes was shown to extend northward to Cadillac. The present discussion aims to bring out the leading features in the reentrant district from the vicinity of Cadillac northward and eastward to the valleys of Manistee and Au Sable rivers. In this reentrant district the recession of the ice border, which was more pronounced than in neighboring parts of either of the lobes, formed several ridges and groups of knolls, which will be considered in order from older to younger.

HARRISON-LAKE CITY RIDGED BELT.

The most conspicuous chain of ridges in the district is one that leaves the West Branch morainic system of the Saginaw lobe immediately east of Harrison and runs northwestward through central Missaukee County to the correlative moraine of the Lake Michigan lobe in Wexford County. It is a narrow but sharply ridged belt with an average width of scarcely 2 miles and relief of 75 to 150 feet. Its highest part is directly north of Cadillac, where it rises slightly above the 1,500-foot contour. In Wexford County much of it rises above the 1,400-foot contour, but in Missaukee County it exceeds 1,400 feet only in the northwest part. From Lake City southeastward only a small part of the crest reaches 1,300 feet, much of it being about 1,200 feet. Narrow gaps 1 to 2 miles wide, in which no traces of the moraines can be seen, are utilized by drainage, one, near the corner of Roscommon, Missaukee, and Clare counties, by Muskegon River, and two, in Missaukee County, by small tributaries of the Muskegon. The ridged belt is thickly set with basins 10 to 50 feet deep and with knolls of corresponding height, so that its surface is about as irregular as that of the interlobate moraine elsewhere. The drift is gravelly and bowlders are not conspicuous. The soil is so much lighter than that of bordering till plains that scarcely any of the ridge has been converted into farm land; however, it once carried a heavy growth of white and Norway pine and hemlock and is well adapted for reforestation.

In Clare County the ridged belt is bordered on each side by sandy plains which once bore Norway pine. In southeastern Missaukee County it is bordered by till plains with rich soil. In northwestern Missaukee County it is largely bordered by sandy plains, though on the north slope, in the western tier of townships of the county, it shows some rather clayey till. In Wexford County it is generally bordered by sandy plains.

Flowing wells are obtained in a gap in the ridged belt at Dolph, in eastern Missaukee County, at depths of 35 to 40 feet. They are reported to pass through "blue clay and putty sand" and to obtain water in sand. Shallow flowing wells 25 to 40 feet deep are also obtained in southern Missaukee County on the till plain west of the ridged belt, there being several in the vicinity of McBain.

The outwash from this ridged belt (see Pl. VII) was southward to the vicinity of Clam River and Clam Lake across the plain lying west of Cadillac. Similar southward outwash to Clam River led across a pitted plain west of Lake City. A short distance east of Lake City a narrow line of glacial drainage passed southeastward to Clam River, and a few miles farther east another somewhat broader line led southward to the same stream. The Clare County portion discharged directly into the Muskegon Valley. The entire outwash both in the outwash aprons and the narrow lines of glacial drainage is a very sandy gravel.

HOUGHTON LAKE CHAIN OF RIDGES.

A weaker and more fragmentary chain of ridges than the Harrison-Lake City belt runs about parallel with it across southwestern Roscommon and northeastern Missaukee counties. It does not make complete connection at the southeast end with the West Branch morainic system of the Saginaw lobe though the southeast end of one of its ridges south of Houghton Lake comes within 3 miles of a projection or spur of the latter system. The ridge south of Houghton Lake has a relief of 60 to 100 feet above the lake and is one-half to 1½ miles wide. It becomes weak west of the lake and is entirely wanting for about 5 miles west of Muskegon River. It is then about as prominent for 5 or 6 miles as on the south side of the lake, beyond which to a strong moraine on the south bluff of Manistee River it is represented only by scattered knolls. This chain of ridges and knolls is largely of gravelly drift, clayey till being noted only near the western end of the ridge south of Houghton Lake. Bowlders occur in moderate number, but are generally inconspicuous. The greater part of the ridge may not make valuable farm land, but it bears some good farms southwest of Houghton Lake The plains immediately bordering this chain of ridges are sandy except in the vicinity of the west end of Houghton Lake, where there is some clayey till. Much of the bordering district is marshy.

A flowing well on a marsh near the outlet of Houghton Lake is 50 feet deep, largely through blue clay.

The glacial drainage from the Houghton Lake chain of ridges was evidently down the Muskegon Valley, for the ridges lie in a sandy plain that extends to the river in southeastern Missaukee and southwestern Roscommon counties.

HIGGINS LAKE SYSTEM OF RIDGES.

Higgins Lake lies between two morainic ridges, each of which is several miles in length. West of the lake the ridges seem to be represented by only a single belt, and east or southeast of it by isolated groups of drift knolls, surrounded by marshy plains that extend to the West Branch morainic system near St. Helen Lake, in eastern Roscommon County. The ridge on the south side of Higgins Lake, if a chain of hills east of the outlet is included, is about 15 miles long and is 1 to 1½ miles wide; it stands 50 to 75 feet above the level of the lake and has a gently undulating surface. The ridge on the north side of the lake is about 16 miles long and less than a mile wide; it sets in at the southeast immediately south of Roscommon village, leads north of west into Crawford County, and then westward through the southern tier of sections to the southwest corner of the county. It there connects with a prominent drift mass covering several square miles in the northeast corner of Missaukee and southeast corner of Kalkaska counties that rises fully 100 feet above the bordering plains and more than 1,300 feet above sea level. The slender ridge that leads from this drift mass eastward to Roscommon has a relief of only 30 to 50 feet and rises but little above the 1,200-foot contour. The knolls southeast from Higgins Lake rise 50 to 75 feet or more above bordering plains. The chain of knolls known as Ninemile Hills and the knolls west and south of St. Helen Lake form a natural continuation of the southern ridge; knolls farther north are probably to be considered a continuation of the northern ridge. The relief above the bordering swamps puts these knolls above the reach of killing frosts in the late spring and some of them bear successful peach orchards. All these knolls and ridges are of loose and generally of gravelly drift containing enough fine-textured material to make them fairly fertile, and they are already largely under cultivation.

The plain bordering these knolls southeast from Higgins Lake and between Higgins and Houghton lakes is reported to have a clay subsoil. The drier parts are under cultivation, but a considerable portion is still covered to a slight depth with water in rainy seasons. East from Roscommon for a few miles and thence southeast to St. Helen Lake a sandy plain borders the clusters of knolls, but the northeast part of Roscommon County is occupied by a fertile till plain. A sandy plain west of Higgins Lake extends southward to the Muskegon River marshes in western Roscommon County.

This system of ridges is distributed along the divide between the Muskegon and Au Sable drainage, the southern border being drained to the Muskegon and the northern to the Au Sable. The glacial waters evidently found their escape down the Muskegon. The outwash, however, seems not to have been carried far from the edges of the ridges, probably because the district to the south has very little fall.

RIDGES SOUTH OF AU SABLE AND MANISTEE VALLEYS.

A somewhat complex series of morainic ridges runs along the south side of the Au Sable Valley from northern Ogemaw and southern Oscoda counties westward across southern Crawford County to the vicinity of Portage Lake; farther west it is continued by a massive moraine running along the south side of Manistee River from Portage Lake westward across southeastern Kalkaska, northwestern Missaukee, and northern Wexford counties.

The outer ridge of this series is a distinct member for 35 or 40 miles. It parts from the West Branch morainic system about 10 miles north of West Branch and 3 miles directly west of Rose City. Instead of turning eastward with the West Branch system it runs northward nearly to the line of Ogemaw and Oscoda counties and there turns abruptly westward. It passes across the southern edge of the southwestern township of Oscoda County and just north of

the Roscommon-Crawford county line for about 9 miles. It makes a slight offset to the north at the valley of South Fork of Au Sable River but continues westward through southern Crawford County 2½ to 4½ miles from the south line of the county. Knolls in southeastern Kalkaska County fill in to some extent the gap between the western end of this ridge and the more massive moraine on the south side of Manistee River. Throughout its length this ridge is narrow, its average width being less than a mile; it is, however, prominent, rising on an average fully 50 feet and in places more than 100 feet above the bordering plains; in a considerable part of its course it stands above 1,300 feet and at a few points in Ogemaw County 1,400 feet or more above the sea. It is composed of loose-textured gravelly drift throughout, but it is on the whole more fertile than the plain on the south, having some fine loamy material mixed with its gravel and coarse material. A productive till plain lies south of this ridge in the northeast part of Roscommon County, but elsewhere the plain on the south is sandy.

From the bend of the West Branch morainic system at the line of Ogemaw and Oscoda counties a sharp ridge runs northwestward about 4 miles into Oscoda County. It leads toward ridges lying south and west of Luzerne in the western range of townships of Oscoda County, but is separated from them by a gap 6 or 7 miles wide, containing a sandy plain. Westward from western Oscoda County along the south side of Au Sable River to the vicinity of Grayling a somewhat intricate system of ridges and sand plains occupies a belt about 5 miles wide, about half of which is morainic; the ridges as well as the plains are sandy.

From the west side of Portage Lake near the west line of Crawford County a strong moraine 2 to 5 miles wide leads down the south side of Manistee River to the western part of Wexford County. It rises 100 to 400 feet above the river, its relief being much greater from northern Missaukee County westward than toward Portage Lake. Its altitude is generally a little above 1,200 feet, and in northern Missaukee County reaches 1,400 feet. The moraine is mainly of loose-textured gravelly drift but includes sufficient fine material along much of its course to make it suitable for agriculture, and it is occupied by several prosperous farming settlements. Tracts of clayey till lie on its inner slope, and narrow plains in places lie between it and Manistee River. A sandy plain, apparently outwash from the moraine, lies along most of its outer or southern border.

This moraine unites in western Wexford County with the Harrison-Lake City ridge, and the combined morainic system runs southward into Lake County. It lies along the western edge of the great Saginaw-Lake Michigan interlobate tract in eastern Lake and Newaygo counties, and its southern portion is not easily separated from that tract. Offshoots from it will be considered later.

RIDGES AT HEADWATERS OF AU SABLE AND MANISTEE RIVERS.

Two of the headwater tributaries of Au Sable River and the headwater portion of Manistee River lead southward from Otsego County into Crawford County through sags between prominent morainic ridges to the vicinity of Grayling, where the Au Sable turns eastward and the Manistee westward through a sandy plain. The ridges stand 100 to 200 feet above the intervening sags; they are highest at their northern ends, attaining an altitude of fully 1,400 feet; their southern ends are somewhat less than 1,300 feet. The ridges from the west branch of Au Sable River eastward appear to have been produced by ice moving westward from the Lake Huron basin, and those west of this stream seem to have been formed by an eastward movement in the Lake Michigan lobe. The central ridges were probably formed before those on either side, for the gravel plains or lines of glacial drainage lead toward the central ridges from those on the eastern and western borders of the system. (See Pl. VII.) The central ridges have at the surface bowldery clay a few feet deep, which was largely covered with maple forest, but which is now being rapidly cleared for farming. Wells indicate that sand sets in at slight depth, commonly 10 feet or less, and extends as far as the wells have been carried, or to 200 feet or more. The ridges on the eastern edge of the system are more sandy and less suitable for agriculture. The central ridges are on the whole less deeply indented by basins than the later ones. Portions of the

eastern ridge are thickly set with basins 50 feet or more in depth. A few points on each ridge rise considerably above the general level, but much of their surfaces is gently undulating.

The drift of the valley-like depressions between the ridges is sandy and rather low in fertility, and consequently scarcely any of the lowland has been brought under cultivation. These plains have a southward slope and were apparently utilized by lines of glacial drainage flowing southward as far as Grayling. Thence the drainage appears to have been westward down the Manistee, for a well-defined channel leads from the Au Sable westward past Portage Lake to the Manistee and is continued along the Manistee Valley. These features indicate that the border of the Michigan ice lobe had withdrawn to the north side of the west-flowing part of Manistee River in Kalkaska, Grand Traverse, and Wexford counties at the time these ridges were being formed. The Au Sable at that time appears to have been covered by the ice from the Huron basin at least as far up as western Oscoda County. These ridges seem to be somewhat younger than the system south of Au Sable River in southern Crawford County, for that system is apparently continued south of Manistee River. Their correlative is probably found in a fragmentary chain of knolls and ridges along the north side of the Manistee Valley.

To the east, north of the Au Sable River, lie extensive sandy plains which bear many basins and some knolls and short ridges. The best-defined ridge lies northwest of Mio; it is of crescent form, curves to the west, and is bordered by a till plain on the east and south. A small lobe of ice seems to have protruded eastward into the Au Sable Valley when this ridge was formed. Near the middle of the ridge, at a point about 6 miles north of Mio, a prominent point rises about 150 feet above the surrounding country, but elsewhere the relief is only 50 to 75 feet.

WEST BRANCH-GLADWIN GROUP OF MORAINES OF THE WESTERN LIMB OF THE SAGINAW LOBE.

By Frank Leverett.

GENERAL FEATURES AND DISTRIBUTION.

The moraines formed by the Saginaw lobe in its recession from the Charlotte morainic system and prior to the readvance marked by the Port Huron morainic system are crowded closely together in the reentrant angles between the Saginaw and Lake Michigan lobes on the one hand and between the Saginaw and Huron-Erie lobes on the other, but are more widely spaced around the end of the Saginaw lobe. They are much more numerous south of the Grand River outlet than they are north of that outlet. The small moraines that branch from the northern portion of the western limb and bridge the reentrant between it and the Lake Michigan lobe are exceptionally complex and have already been treated (pp. 229–231). Here only the moraines along the Saginaw lobe north of the Grand River outlet are discussed; those at the end of the lobe and those on its eastern side are discussed later by Mr. Taylor (pp. 238–244). The western limb of the Saginaw lobe has strong development as far northeast as the bend of Au Sable River in Alcona County.

The portion of the bulky series of moraines between Au Sable River and Harrison, termed the West Branch morainic system, is 4 to 8 miles in width. (See Pl. VII, in pocket.) It follows the line of Oscoda and Ogemaw counties westward from Au Sable River for about 15 miles, runs southward for an equal distance through central Ogemaw County, turns southwestward near West Branch, and continues for about 30 miles across southeastern Roscommon and northwestern Gladwin counties to Harrison in Clare County. There is some development of parallel ridges separated by narrow gravel plains or lines of glacial drainage in the portion between West Branch and Harrison, but northeast from West Branch there is only a single massive moraine.

In southern Clare County the West Branch morainic system separates into an outer strong moraine and an inner relatively weak one. The outer moraine, however, becomes separated a few miles farther southwest, in eastern Mecosta County, into two moraines, each of considerable strength. These two moraines bear southeastward across southwestern Isabella County

into Montcalm County, where they turn southward across eastern Montcalm and northeastern Ionia counties to the Grand River valley. Just north of the river the outer of these moraines splits into three and the inner into two members.

The relatively weak inner moraine passes southward from southeastern Clare County through western Isabella County 2 to 5 miles from the inner edge of the stronger moraine. It crosses Chippewa River at the great bend a few miles west of Mount Pleasant, assumes considerable strength for a few miles, and bears southeastward into northwestern Gratiot County, its width being increased from less than 2 miles to about 4 miles. It then runs southward with diminishing strength through the western edge of Gratiot County to the Grand River outlet in the northwestern corner of Clinton County.

A small moraine, termed the Gladwin, lies east of the strong West Branch morainic system, with which it is connected only at its north end in southwestern Ogemaw County. It passes southwestward into northern Gladwin County, where it is interrupted for a few miles. It sets in again about 5 miles northeast of Gladwin and leads southwestward, passing just north of that town across western Gladwin County. It continues across southeastern Clare to central Isabella County just west of Mount Pleasant, crosses Chippewa River, and goes southeastward into Gratiot County. A ridge parallel to it on its inner border leads southeastward from just east of Mount Pleasant to St. Louis in Gratiot County. The two ridges unite near Ithaca and run southward to the Grand River outlet. From the outer ridge a spur leads southward from the northern part of Gratiot County to Elwell and may be continued a few miles farther south in a ridge that runs from about 3 miles southwest of Ithaca southward to the Grand River outlet. It thus appears that this moraine, which is a single ridge in the district north from Mount Pleasant, is separable into two and in places into three ridges between Mount Pleasant and the Grand River outlet. Beyond that outlet it finds continuation in the Flint moraine discussed by Mr. Taylor (pp. 241–243).

TOPOGRAPHY.

ALTITUDE.

The highest part of the West Branch morainic system is in southeastern Roscommon County, where it reaches an altitude of about 1,400 feet. A considerable part of it, from Harrison northeastward to Au Sable River, is above 1,200 feet, but its inner border falls to less than 1,000 feet. The interlobate spur between Au Sable River and the Lake Huron shore in Alcona County is largely above the 900-foot contour and in places above the 1,000-foot contour, and within 2 or 3 miles of the shore of Lake Huron it has points fully 800 feet above sea level, or more than 200 feet above lake level.

From Harrison southward the West Branch morainic system shows a steady decrease in each of its members clear to the Grand River outlet. The outer members are each a little higher than the next inner one throughout this entire distance. The outermost member near Ionia stands over 800 feet above sea level at the bluff of the Grand River outlet; the second is nearly 800 feet where it comes to the bluff; the third is but little above 700 feet at the bluff in northwestern Clinton County. The outer member shows the greatest range—about 600 feet—in altitude; the inner member, or rather the inner edge of the main system, descends little more than 300 feet from the border of the Au Sable Valley to the Grand River outlet.

The Gladwin moraine stands above 900 feet for a few miles in southwestern Ogemaw County and mainly between 800 and 900 feet from the Ogemaw County line to the Chippewa Valley at Mount Pleasant. A small tract in southeastern Clare County stands above 900 feet. From Mount Pleasant southward the 800-foot contour is reached only for a short distance in southeastern Isabella County. Elsewhere between Mount Pleasant and the Grand River outlet the altitude is between 700 and 800 feet.

RELIEF.

The relief of the moraine above the inner border district is greatest in Ogemaw and Roscommon counties, amounting in places to nearly 500 feet, and throughout much of the distance from Au Sable River to southern Clare County is more than 200 feet. Southward

from Clare County, where the West Branch morainic system is separated into several members, the relief of each ridge is less than 100 feet except in northwestern Isabella and eastern Mecosta counties, where it is 200 feet or more.

Along the outer face of the West Branch morainic system throughout its entire length from the Au Sable Valley to the Grand River outlet, the relief is moderate, being generally less than 100 feet. In northern Clare, southeastern Roscommon, and western Ogemaw County, however, it in places reaches 200 feet.

The relief of the Gladwin Ridge is not more than 50 feet on either border except in Isabella and southeastern Clare counties, where it reaches nearly 100 feet on the inner border.

CHARACTER.

The closely crowded parallel ridges of the more massive portion of the West Branch morainic system become more and more distinctly separated in passing southward to the Grand River outlet. They are broken by a few gaps through which streams have passed from the outer border district into the inner border plain, the most conspicuous being that utilized by Chippewa River, which heads in the plains in southwestern Clare County and makes its way through each and all the members of the system to the inner border plain at Mount Pleasant. Pine River also cuts through several of the morainic ridges at places where they were weakly developed.

The great majority of the knolls through the entire length of the morainic system are relatively inconspicuous, but in a few places they rise to 100 feet or more, the most conspicuous being in the highest part in Roscommon and neighboring parts of Clare and Ogemaw counties. Ranges of hills in eastern Mecosta County also rise above 100 feet, but from the latitude of Mount Pleasant southward the moraines generally are composed of low knolls. A few knobs in the vicinity of Stanton are 100 feet more or less in height, but these seem to be outside the system under discussion and were apparently formed during the retreat of the ice from the Charlotte morainic system.

Basins are conspicuous along the entire massive morainic belt and along its constituent members toward the south. Many of them contain shallow tamarack swamps, but not a few hold small lakes.

The Gladwin Ridge has a swell and sag topography with fewer basins than characterize the main system. Its most hilly part is in Ogemaw County, where it also carries basins and some lakes.

STRUCTURE OF THE DRIFT.

The outer portion of the massive morainic tract from Au Sable River southwestward to Mecosta County, west of Mount Pleasant, contains a large percentage of gravel and sand, but much of its inner border carries a clayey till. In consequence much of the inner slope has been converted into farming land, and the outer is in large part a desolate waste in which brush is growing up to take the place of the pine forests that have been removed. In places the productive agricultural lands extend nearly to the outer border of the morainic system, for instance northeast and west of Harrison and in the northwest corner of Isabella County. The greater part of the outer slope of the morainic system, however, seems better suited for forest than for agriculture.

The greater portion of the morainic system from Clare County southward to the Grand River outlet has a soil suitable for productive farming and is largely under cultivation; the moraines are better farming land than the depressions that separate them, the latter being sandy and swampy lines of glacial drainage. In Gratiot, Montcalm, and central Isabella counties the moraines are separated by broader strips of fertile till plain, which lie on the inner slopes of the moraines and not, like the drainage channels, on the outer slopes. The constant repetition of the series, drainage channel, moraine, and till plain, brings out clearly the glacial and fluvioglacial relations and conditions.

The Gladwin moraine has sufficient till along its entire course to render it profitable for agriculture, but in the gaps in northeastern Gladwin and southeastern Ogemaw counties and at Au Sable River in northwestern Iosco County its soil is relatively inferior, much of it being a light sand. There is also a sandy tract all along the outer border of this moraine from Au Sable River to the Chippewa, very little of which has been brought under cultivation.

Bowlders and cobblestones are conspicuous on the surface and in the upper part of the drift on the outer face of the main morainic system from the Au Sable Valley to within a few miles of the Grand River outlet but are relatively inconspicuous in southeastern Montcalm and northeastern Ionia counties. On the inner slope bowlders are common.

On the Gladwin moraine bowlders are conspicuous in parts of Ogemaw and Iosco counties, but as a rule they are not much more numerous than on the bordering plain and are less abundant than on the West Branch morainic system.

As the principal settlements are along the inner or eastern face of the large morainic belt in Ogemaw and Claire counties, and as no extensive settlements have been made in Roscommon and Gladwin counties, information is rather fragmentary concerning the deeper parts of the drift. In the interlobate spur in Alcona County the wells are shallow, but some deep ones on its south border at Killmaster show that the thickness of the drift is great. Deep wells at Mount Pleasant, Gladwin, Alma, St. Louis, and Ithaca, along or near the line of the small moraine east of the main system, also show a great thickness of drift in this low-lying district. There is no reason for suspecting the rock surface to have a greater altitude beneath the main morainic system than in this district, and it is probable that the higher ridges bear as much as 700 feet of drift. The following table sets forth the altitude of the bedrock, so far as known, along the inner edge of the morainic system:

Altitude of bedrock surface along and east of the West Branch morainic system.

Location.	Altitude of well mouth.	Thickness of drift.	Altitude of bedrock.	Remarks.
	Feet.	*Feet.*	*Feet.*	
Rose City, heading mill	935	233	702	Well is 241 feet.
West Branch, livery	953	180	773?	Bits of coal near bottom. Rock doubtful.
Edwards Lake, sec. 28, T. 21 N., R. 1 E	850	203	647	Well is 238 feet.
Chapman Lake, sec. 32, T. 21 N., R. 1 E	840	185	655	Well is 403 feet.
Gladwin waterworks	765	160	605	Well is 465 feet.
Estey, sec. 25, T. 17 N., R. 2 E	700	140	560	Well is 300 feet.
Clare, coal boring	834	275+	559−	Stops in quicksand.
Five Lakes, sec. 16, T. 17 N., R. 4 W	900	280+	620−	No rock struck.
Mount Pleasant, bromine well	770	435	335	Well is 1,585 feet.
St. Louis, Harrington well	753	335	418	Well is 600 feet.
St. Louis, Andrews well	753	203	550?	Rock may have been struck (shale).
Alma Sanitarium	756	500	256	Well is 2,863 feet.
Ithaca	751	330	421	Well is 613 feet.
Ashley	670	50	620	Well is 275 feet.
Ashley, 1 mile north of	675	190+	485−	No rock struck.

The well sections given below are among the deepest obtainable. They are taken in order from northeast to southwest, beginning in northeastern Ogemaw County.

Isaac Lupton's well, 1½ miles north of Lupton, at an altitude about 1,050 feet, is 125 feet in depth and penetrated only 16 feet of till, the remainder of the section being sand.

In and around Rose City, which stands at the eastern base of the large moraine, many strong flowing wells appear to obtain water from gravel beds interbedded with till at different horizons.[1]

At Campbells Corners, at an altitude of about 1,080 feet, a well made by James Campbell penetrated 10 feet of till and 120 feet of sand to its bottom.

At West Branch wells sunk by C. J. Blakeley and C. J. Phelps to depths of 185 and 152 feet, respectively, penetrated a large amount of till and near the bottom entered sand containing bits of coal. The water flows with a strong head and frequently brings up coal. It is doubtful, however, if the bottom of the drift was reached.

[1] Water-Supply Paper U. S. Geol. Survey No. 183, 1907, p. 291.

A well at Georges Lake, in sec. 18, T. 21 N., R. 2 E., penetrated 19 feet of till, 91 feet of sand and gravel, and 60 feet of a gray clay called "soapstone," beneath which lay gravelly clay and then sand to a depth of 214 feet. The "soapstone" may be only a hard till.

A well at Edwards Lake, in sec. 28, T. 21 N., R. 1 E., penetrated sandy clay 48 feet, sand 112 feet, red clay 10 feet, and red sand 33 feet, beneath which sandstone was struck at a depth of 203 feet. The well was continued in rock to a depth of 238 feet.

At Chapman Lake, in sec. 32, T. 21 N., R. 1 E., a well penetrated clay 30 feet, gravel and sand 70 feet, sandy clay 50 feet, sand 20 feet, and gravelly clay 15 feet, below which alternations of sandstone and other rock formations extended from 180 to 403 feet.

Jacob Schwartz, 1 mile north of McClure, Gladwin County, made several flowing wells just north of the small ridge which runs past Gladwin; they are about 100 feet in depth and are largely through a clayey till. Other borings in and around Gladwin pass through considerable till with thin beds of gravel and sand from which they obtain flowing wells; some, however, are carried into the rock.[1]

OUTER BORDER.

From Mecosta County northward the district outside West Branch morainic system is largely occupied by sandy outwash aprons, which drained southwestward through Muskegon and Little Muskegon rivers. The outwash has an altitude of about 1,200 feet in southern Oscoda County and in much of Roscommon County, but from southwestern Roscommon County it slopes rapidly southwestward down the Muskegon Valley. In Mecosta County the glacial drainage led southward and westward through the Little Muskegon Valley.

In Montcalm County the border is very complex. Its limits are less definite than in districts to the north, and there is some uncertainty as to where they should be drawn. The best-defined moraine runs past Edmore and just east of McBride and Stanton, and then swings southwestward toward Amsden. But outside of this there is a district in which sharp knobs and clusters of hills are surrounded by nearly plane tracts. West of these knobs and the surrounding till there are tracts of nearly plane sandy gravel, which may perhaps be an outwash from the ice border at the time the sharp knolls were forming. If these knolls are included in the West Branch morainic system the border runs nearly directly south from southeastern Mecosta County across Montcalm County and passes just west of the city of Stanton. Mount Dodge, the highest of the knobs, situated 1½ miles northwest of Stanton, has an altitude of about 190 feet above Stanton station, or 1,082 feet above sea level. From it lower knolls extend a short distance southwest and west, and a sharp range of hills leads northward about to Westville, a distance of 4 miles. These are all gravelly kames, and the district immediately west is a plain of sandy gravel, probably an outwash.

A small esker at the north end of this range of hills leads northwestward for 3 miles from near the Pere Marquette Railroad about a mile south of McBride across secs. 17 and 7, Day Township, and sec. 1, Douglas Township. The esker is 10 to 20 feet in height, but has several small gaps. It lies in an esker trough, which is rather obscure at the southeast end, but is well defined from sec. 7, Day Township, northwestward beyond the end of the esker to the Flat River valley in sec. 28, Belvidere Township. Its width is one-half to three-fourths of a mile, and its surface is 10 to 20 feet or more below the bordering plain. Its extension beyond the esker is through a tract of sandy till.

Northern Belvidere Township, Montcalm County, and northeast Cato Township are dotted with sharp knolls 50 to 75 feet high, but much of their surface is very gently undulating. The knolls are gravelly, but the undulating tracts consist of a loose-textured, sandy to gravelly till that seems to merge at the northwest into the great outwash plain along the Little Muskegon River. This district adjoins a strong moraine in Millbrook Township, Mecosta County, which also fronts on the outwash apron. The features strongly support the inclusion of this knolly undulating tract with the morainic system under discussion, though as already indicated a line of stronger morainic features leads southeastward from Millbrook Township toward Edmore.

[1] Water-Supply Paper U. S. Geol. Survey No. 183, 1907, p. 114.

The district southwest from Stanton as far as Greenville and thence southward along the east side of Flat River into Ionia County is characterized by a large number of basins, some of which cover 1 to 2 square miles or more. Knolls, however, are low and scattered, and the greater part of the surface is nearly plane. The drift varies greatly in texture, some of it being loose and gravelly and some being a typical till. Gravel and sand, however, predominate greatly over till for 4 or 5 miles east of Flat River, from the latitude of Stanton southward about to Greenville. The till is best exhibited in a belt 3 to 4 miles wide leading from Stanton southwestward through central Sidney Township and western Fairplain Township. Immediately east of this belt of till lies the morainic belt which may prove to be the outer member of the system under discussion. At present, however, it seems more probable that the ice at the beginning of the development of this morainic system extended across Montcalm County about to the Flat River valley. The basin tract under discussion continues southward across northwestern Ionia County, crosses the Grand River outlet near Saranac, and continues about to Morrison Lake, where it turns southeastward toward Lake Odessa, keeping just east of the eastern member of the Charlotte morainic system. Till is more conspicuous on the plane tract around the basins and is more clayey in Ionia County than it is in Montcalm County.

GLACIAL DRAINAGE.

A strong line of glacial drainage seems to have led along the line of Montcalm and Ionia counties into the Flat River valley near Belding. With the recession of the ice this drainage was extended eastward to northwestern Ronald Township, Ionia County, just east of Shiloh. Its channel, which was 3 to 5 miles wide, including a few small knolls around which the glacial drainage apparently passed, received a feeder from the north along Dickinson Creek from near Amsden. On either side, in Fairplain Township, Montcalm County, and in Orleans Township, Ionia County, lie the tracts of gently undulating till containing the large basins that are discussed above.

The Grand River outlet, whose features have been studied more particularly by Mr. Taylor (pp. 255, 360), probably served as a strong line of glacial drainage throughout the development of this morainic system.

Between the outer and second of the constituent ridges of the system in southwestern Isabella County a gravel plain sets in and leads southeastward into Montcalm County nearly to Vestaburg. The river passes eastward through the moraine on which Vestaburg stands, but the glacial drainage probably continued southward through a series of narrow channels in western Ferris Township to a well-defined line of border drainage in secs. 19 and 30, Ferris Township, which continues southward along the west edge of the moraine to the Grand River outlet in Ionia County. Its general width is about a mile, though in places it narrows to less than one-half mile. The descent of this border drainage is about 200 feet in 50 miles from its head in southwestern Isabella County to the Grand River outlet (from 900 to 700 feet above sea level). The material along the whole line of the channel, so far as seen in exposures, is fine sandy gravel, scarcely coarse enough for road ballast.

The line of glacial drainage between the second and third moraines is continuous from southern Clare County to the Grand River outlet, a distance of about 70 miles. It heads near Hatton and passes southwestward, leaving Farwell at its east border, and enters the Chippewa Valley drainage in northwestern Gilmore Township, Isabella County. It then passes south to the bend of the Chippewa west of Mount Pleasant, from which point the water may have led westward into the valley of Pine River through a break in the second moraine and thence to the Grand River outlet along the line just outlined. Or, more probably, its greater part may have passed southward by Dushville through a swampy depression which drains into Pine River in northwestern Gratiot County, followed Pine River past Riverdale to Sumner, and continued southward to the Grand River outlet along the line of Gratiot and Montcalm counties. At its source this second line had an altitude of about 1,000 feet and descended 300 feet to reach the Grand River outlet. Its width ranges from 1 mile or less up to 5 miles. In much of its course

across Isabella County it is spread out in a plain 2 to 5 miles wide, composed largely of fine sandy gravel, as in the glacial drainage line to the west.

The glacial drainage connected with the Gladwin moraine probably passed southwestward through narrow channels between morainic ridges in western Gladwin and southeastern Clare counties, though the details have not been worked out. From the village of Clare a well-defined border drainage channel, filled with a sandy outwash, leads southwestward to the Chippewa Valley, southward from which a depression on the outer border of the moraine leads into Gratiot County. So far as noted this depression is nearly free from sand or gravel deposits, but it seems likely, nevertheless, to have been followed by the glacial waters. In Gratiot County a low plain lies west of this weak morainic belt but appears to bear little outwash. The writer has not made a detailed study along the morainic belt, but there appears to have been no obstruction to the southward passage of water along the outer edge of the ice into the Grand River outlet through western Gratiot County.

MORAINES OF THE EASTERN LIMB OF THE SAGINAW LOBE.

By Frank B. Taylor.

DISTRIBUTION.

GENERAL FEATURES.

The moraines of the southern and eastern borders of the Saginaw lobe lie between the Grand River channel and the west line of Lapeer County. Grand River channel, which will be fully described later (pp. 255–259, 360), extends westward from Gratiot County to Lake Michigan. It is occupied from southeastern Gratiot County by Maple River, which flows westward and southwestward as a sluggish stream wandering on a swampy floor of a mile-wide valley. It is entered from the south by Grand River at Lyons, about 40 miles east of Grand Rapids, and it takes its name from that stream throughout its length of about 75 miles. It cuts directly across the West Branch-Gladwin group of moraines, on a line a little north of the central axis of the Saginaw Valley produced southwestward.

That part of the West Branch-Gladwin group of moraines which lies north of the Grand River channel (described by Mr. Leverett, pp. 232–238) generally shows much complexity in the northern part of the State, although clearly separate from other moraines which preceded and followed it.

North of West Branch the deposits have the appearance of a single massive moraine of irregular form, but in their extension southward to the vicinity of Harrison and Gladwin they change remarkably to a complex of short morainic ridges, overlaps, spurs, loops, and irregular knolly patches. Farther south they divide and spread more and more widely into separate individuals with roughly parallel courses. At the north side of the Grand River channel the deposits have a width of nearly 40 miles, and 5 to 10 miles farther south their slender ridges are more perfectly set apart as individuals, spreading over a width of more than 50 miles. This change in form from an essentially single, massive individual to many slender, distinct individuals is not equaled in any other locality now known.

The distribution of the moraines in the district is dependent in part at least on the relation of the Saginaw ice lobe to the topography. As the ice advanced out of the deeper basin of Lake Huron, it deployed on all sides upon a relatively smooth plain that sloped very gently upward in all directions. The upward slope was a little less toward the south than toward the west and was still less toward the southwest. The ice adapted itself to the form of the wide, shallow basin with minute fidelity. Its front took on an unusually symmetrical form, now revealed by the configuration of the terminal moraines. A straight line drawn from the center of Saginaw Bay (about 20 miles northeast of Bay City) southwestward to the village of Hastings in Barry County divides the moraines into almost perfectly symmetrical halves. The symmetry is perhaps a little more perfect if the division is along a line 5 to 10 miles southeast of and parallel with the real axis. The best developed area is in Clinton, Ionia, Shiawassee, northern Eaton, and

southern Saginaw counties and extends almost as perfectly into Genesee County. In this area the moraines are remarkably parallel for about 85 miles. In the typical area they are so remarkable for the simplicity of their configuration and grouping that it seems important to describe them somewhat fully.

Where the morainic ridges are most typical and most widely deployed they are all of about the same strength and are almost equally spaced, indicating apparently that they are all fully developed single individuals of their class, and that no one of them represents a combination of two or more such individuals. In Clare and Montcalm counties some of the more massive ridges come within 6 or 8 miles of the Grand River channel before they divide into their ultimate units, but all the ridges that cross the channel appear to be single individuals.

These slender moraines number a dozen or more, each named for some city or village through or near which it passes. Their names, beginning with the oldest, are as follows, the last three being water-laid and fainter than the rest: (1) Lansing, (2) Grand Ledge, (3) Ionia, (4) Portland, (5) Lyons, (6) Fowler, (7) St. Johns, (8) Flint, (9) Owosso, (10) Henderson, (11) West Haven, and (12) Chesaning; still another very faint member lies north of the Chesaning. Possible equivalents of the Flint moraine are the Maple Rapids and Eureka ridges.

Where deployed in open order these slender moraines possess characteristics very different from those of most of the other moraines of Michigan. They are predominantly clayey, generally yellowish gray or brownish gray on weathered surfaces, and they contain comparatively few bowlders and small quantities of pebbles or water-assorted materials. Their width varies from one-eighth mile to 2 miles, averaging about 1 mile, and rarely exceeding 1½ miles. Their relief above the adjacent flat till plains is generally low and as a rule their surfaces are comparatively smooth. The highest knoll in any of them, where they stand apart as separate individuals, does not exceed 60 feet above the plain and their average crest height does not exceed 20 feet. In some places they fade out to a broad, low swell scarcely perceptible to the eye and in other places to scattered low knolls scarcely 5 feet in height.

Where these moraines overlap—the later ones overriding the earlier—as they do eastward from Lansing, their characteristics are entirely different. They become broken and irregular—more massive, wider, and higher in places, more steep-sided, and more rugged. Their normally even trend is destroyed and they include many lakes and swamps in reentrants and transverse and irregular depressions. In these areas they resemble more nearly the massive rugged moraines of other parts of Michigan, except that they are narrower and smaller.

LANSING MORAINE.

The relatively massive West Branch morainic system crosses the north line of Ionia County and runs southward. About 4 miles from the line it divides into three slender moraines which diverge toward the south and southwest. The most westerly of the three reaches the Grand River channel about 3 miles west of Ionia, at which place it is about 1½ miles wide. This is the northern limb of the Lansing moraine. Beyond the channel for about 10 miles south no certain continuation exists, but 3 or 4 miles northwest of Lake Odessa scattered morainic knolls appear, and from the east bank of the lake a well-defined but very slender moraine, here called the Lansing, extends eastward through northern Eaton County to the southern part of Lansing, a distance of over 25 miles, passing through the villages of Lake Odessa, Sunfield, and Mulliken. Where it passes about 2 miles south of Grand Ledge this moraine is extremely narrow though sharply defined. For 5 or 6 miles in T. 4 N., Rs. 3 and 4 W., it is hardly one-eighth mile wide, but it is perfectly continuous, and although it is only 10 to 20 feet high, is conspicuous above the flat till plains on either side. Elsewhere its usual width is from three-fourths of a mile to a mile.

At Lansing the moraine is cut through by Grand River and by Sycamore Creek, and becomes otherwise broken and irregular where it passes over the north end of the Mason esker. Eastward it extends in broken, irregular form at least as far as Okemos, but beyond this its exact course is uncertain. It may possibly run eastward along Cedar River, passing in very faint

form just north of Williamston. A more probable course, however, is northeastward from Okemos past Pine Lake and Alverson, where it either turns abruptly southeast or is combined with the next later moraine. The region of marked overlapping extending eastward from Okemos will be described later (pp. 244–245).

GRAND LEDGE MORAINE.

The second slender moraine of the series, known as the Grand Ledge moraine, comes down to the north bank of the Grand River channel about 2 miles west of Ionia, between the Pere Marquette Railroad and Bellamy Creek, and is there very narrow, hardly more than a quarter of a mile wide. On the south side of the channel, beyond a break of about 2 miles, it reappears, but for 3 miles it is very slender, being scarcely more than one-eighth mile wide. Toward Orange it grows stronger, its width being about three-fourths of a mile. For about 8 miles from the channel it runs a little east of south, but a mile south of West Sebewa it turns east-southeast and passes just north of Cornell and Danby, close along the south side of Grand River as far as Grand Ledge, though it is much broken for 4 miles west of this place. East of West Sebewa it is about a mile wide and 15 to 30 feet high. The main part crosses to the north of the river at Grand Ledge and is higher and stronger for 7 or 8 miles east. From Grand Ledge it runs directly east to a point about 2 miles north of Lansing, where it turns southeast. Northeast of Lansing it is more than a mile wide and unusually high. This section of the moraine runs about 4 miles southeast to the Michigan State Agricultural College, where it abruptly turns nearly 90° to the northeast, forming a small, sharply pointed lobe, with the college about one-half mile west of the apex. At the apex the moraine is broken by glacial drainage which issued toward the south. Two miles northeast of the college the moraine is again strongly developed and continues so to the north side of Pine Lake. North from the apex and partly inclosed by the strong limbs of this small lobe lies the great Chandler Marsh, probably a shallow lake formerly and now the largest marsh in this part of the State.

IONIA MORAINE.

The third or Ionia moraine comes down from the north and curves sharply to the southwest just before entering Ionia. In the northern part of the city it is about 2 miles wide and 20 to 25 feet high. South of the channel it curves southeast a little more directly than the Grand Ledge moraine and keeps in close parallelism with it nearly to Lansing. It crosses Grand River about 2 miles south of Portland and follows its north side to Eagle. Beyond this it becomes broken and irregular, like the others, but continues almost directly east to the southwest corner of Genesee County, passing south of Wacousta and Dewitt and through Gunnisonville and Bath. Farther east it passes just north of Shaftsbury and East Cohoctah, where it appears to be overridden by a later moraine. From Ionia to Bath it is rather more slender than the earlier ridges, but gains in strength toward the east.

PORTLAND MORAINE.

The next moraine of the deployed group, known as the Portland moraine, comes down to the north bank of the Grand River channel about 2 miles west of Muir with a width of about a mile. Directly opposite on the south side and about 1½ miles southwest of Lyons it reappears and runs southeast, crossing Grand River east of Collins, and forming the high bluff on the north side of Lookingglass River at Portland. Beyond this it curves gradually toward the east, keeping close to the north side of Lookingglass River and crossing to the south side just east of Dewitt, about 7 miles north of Lansing. Thence it runs east through the northern part of T. 5 N., Rs. 1 W., 1 E., and 2 E. (Bath, Woodhull, and Perry townships), passing the hamlets of Perry and Grass River, and trending a little south of east through the central part of T. 5 N., R. 3 E. (Antrim Township) and across the southwest corner of Genesee County, where it appears to override the Ionia moraine. This moraine is somewhat stronger than the Ionia moraine.

LYONS MORAINE.

The next moraine, the Lyons, comes down to the north bank of the Grand River channel about a mile northeast of Muir and begins again on the south side a mile east of Lyons. From this point it runs southeast past Westphalia and Riley post offices and thence eastward to Laingsburg. Near Westphalia and Riley it is very weak, scarcely traceable, but is stronger farther east. Three or 4 miles east of Laingsburg it crosses Lookingglass River and runs east-southeast to the southeast corner of Shiawassee County, where it appears to override the next earlier moraine. It runs on east in broken form, passing Argentine and a little north of Fenton, turns northeast through the extreme northwest corner of Oakland County, and passes a little south of Atlas into northeast Lapeer County. This moraine seems slightly weaker than the Portland moraine.

FOWLER MORAINE.

The Fowler, one of the finest moraines of the group, comes from the north to the Grand River channel at Matherton about 12 miles northeast of Ionia. South of the channel it runs southeast, passing a little west of Fowler. About 4 miles southeast of Fowler the moraine crosses to the south side of Stony Creek and loses its strength, continuing for 5 or 6 miles as a faint and broken feature. Beyond this, however, it is stronger, and though rather narrow continues as a sharply defined ridge through T. 6 N., Rs. 1 W., 1 E., and 2 E. (Victor, Sciota, and Bennington townships). Its height is in places 40 to 50 feet. Two miles east of Hartwellsville it turns southeast, crosses Shiawassee River, and follows its north side to Linden, whence it runs northeast near Grand Blanc and east of Davison, turns more nearly north, and enters Lapeer County about 2 miles northwest of Elba. Through Shiawassee and Genesee counties this moraine is sharply defined. Between Byron and Grand Blanc it passes along the north side of a jumbled, overlapped area, but is sharply separated from it by a well-defined valley, which contains Shiawassee River and a number of lakes.

ST. JOHNS MORAINE.

The identity of the St. Johns moraine north of the Grand River channel is uncertain. At St. Johns it is a narrow sharp ridge rising 30 to 40 feet above the plain to the north and about 20 feet above the plain to the south. From St. Johns it curves gradually northwest, diminishing in strength for about 5 miles, when it ceases to be a ridge and for a mile or two is represented by scattered knolls that finally die out. Its course indicates that it should reach the Grand River channel 2 or 3 miles below Maple Rapids. But no distinct moraine comes to the channel in that vicinity, nor is one recognizable south of the channel for 6 or 7 miles.

Eastward from St. Johns to within a mile of Shepardsville the moraine is rather faint and broken, with low parallel ridges north of a rather weak main ridge. Farther east it is much stronger, with an average width of a mile, and runs a little south of east across Shiawassee County, crossing Shiawassee River at Newburg, and continuing in the same general direction to a point 3 miles southeast of Gaines in Genesee County, where it turns sharply northeast, passing a mile south of Rankin. To Thread River south of Flint the front ridge is fairly strong. In T. 6 N., Rs. 5 and 6 E. (Gaines and Mundy townships), it is accompanied by later, weaker, fragmentary, approximately parallel ridges that lie 1 to 4 miles north of it. From Thread River to near Richfield it is very faint, being represented only by low, scattered knolls. This weakness is probably due to a narrow lake which lay along the front of the ice southwest from Richfield at this stage of retreat. Crossing Flint River from near Richfield the moraine grows much stronger and higher toward the northeast, and then bends abruptly eastward and passes into Lapeer County.

FLINT MORAINE, BOWLDERY BELT, AND OTISVILLE MORAINE.

The village of Maple Rapids is barely within the head of the Grand River channel. One mile east of Perrinton, which is 6 miles north of Maple Rapids, a sharply defined, narrow till ridge, known as the Perrinton Ridge, runs north and south. Another stronger moraine runs south

from Ithaca along the line between T. 10 N., Rs. 2 and 3 W. (Newark and North Star townships) and then turns southwest through central T. 9 N., R. 3 W. (Fulton Township) to the Grand River channel north of Maple Rapids. (See fig. 1, p. 258.) The first ridge, which appears to have run southward from near Perrinton across the channel 1 or 2 miles northeast of Maple Rapids, is clearly out of harmony with the second, which appears to project as a sharp tongue down the channel. It looks as if the first moraine was built before the channel was in existence, and that the second one came later, after the channel had been made, and that the ice was guided by the channel in the formation of the sharp tongue. The topography on the south side of the channel seems to support this view, for the moraines there are broken and irregular, though two main ridges corresponding to the two on the north side are easily made out. The first, which may be called the Flint moraine, seems certainly to be a continuation of the Perrinton Ridge, which would run into it if produced southward. It begins abruptly on the south side of Maple River as a high, steep bluff rising close above the stream. For 2 or 3 miles to the southeast it runs as a double ridge with a small, narrow clay flat between, the eastern ridge being the smaller of the two. From this on for 9 or 10 miles east to Duplain it is represented only by scattered knolls in a flat clay plain which is sometimes swampy.

Beyond Duplain it reappears as a strong ridge and 2 miles east of the village makes a sharp loop to the north around a flat hollow about 2 miles in diameter. This hollow is almost surrounded by the moraine, remaining open only to the southwest. On account of this irregularity the moraine has unusual breadth north of Ovid. East of Ovid it is cut through by an esker trough which enters from the northeast, turns west, and runs nearly parallel with the moraine. At its mouth it contains an esker nearly a mile long, which also parallels the moraine, a very exceptional course for an esker.

Some of the irregularities in this moraine from Maple Rapids to Ovid may be due to a readvance of the ice, but others appear to be due directly or indirectly to the presence and influence of the great outlet river which flowed close along the front of the ice at that time.

The moraine grows unusually wide again south and west of Owosso and is cut through by a wide, low trough. Shiawassee River cuts through it at Vernon and a smaller stream northwest of Duffield. With these exceptions it runs with even strength from Ovid to Flint. It is prominent and controls much of the drainage. From Ovid to a point north of Durand it runs a little south of east, but between Vernon and Duffield it curves gradually around through east to east-northeast and keeps this direction to Flint. From Corunna east it is half a mile to a mile wide and rises 30 to 50 feet above the channel floor south of it. Its trend on entering the western part of Flint is east-northeast.

Flint seems to be situated at the former apex of a blunt ice lobe, for a probable continuation of the moraine runs north from the north side of the river nearly to Mount Morris and there turns northeast and passes near Thetford into Tuscola County. Flint River here follows the last position of the Imlay outlet channel. It enters Flint from the northeast and turns west-northwest, cutting a gap about a mile wide through the moraine. The moraine on the north bank is weaker for 2 or 3 miles than the one west of Flint and seems to stand somewhat out of line with it, even if the apex of a lobe was at Flint. Still, it is almost certainly the continuation of the Flint moraine. The lack of alignment suggests that the part north of the river may represent only the inner part of the Flint moraine.

Other facts give some support to this supposition. A well-defined bowlder belt which runs northeast from Flint to the river south of Rogersville rests on the flat till plain, but may represent the continuation of the outer part of the Flint moraine, for the morainic features farther northeast seem to require the continuation of the ice front across this bowldery interval.

Another strong morainic area lies just south of the river on the township line east of Genesee and still another smaller one on the north side a mile northeast of Genesee; perhaps both belong to the Flint moraine, but their relations are not entirely clear. In the northwestern part of Richfield north of the river, however, morainic knolls appear and increase rapidly in strength and continuity toward Otisville, forming what may be termed the Otisville moraine. They grow still stronger farther northeast on the north side of the railroad to and beyond the

corner of the county. The morainic features are very irregular, but the moraine has outwash at several points on its east side and is sharply separated from the next later moraine by a strong line of ice-border drainage which follows Butternut Creek toward the southwest. In passing northeastward out of Genesee County this moraine bends a little to the east and crosses the extreme northwest corner of Lapeer County. Its front passes just north of Otter Lake, north of which for a mile or more it is very high, reaching an altitude of over 1,000 feet above sea level.

The bowlder belt northeast from Flint appears to follow the normal course of the Flint moraine produced, and the Otisville moraine continues in the same line. If the moraine running north from Flint is the continuation of the Flint moraine, the bowlder belt and the Otisville moraine appear to be left as detached fragments out of harmony with the earlier and later members of the group and without visible representation toward the west. The Otisville moraine is roughened, as if by overriding some earlier moraine or other feature of considerable relief. Though the preponderance of evidence seems to favor the ridge going north to Mount Morris as the continuation of the Flint moraine, the alternative course past Otisville remains open.

OWOSSO MORAINE.

The Owosso moraine passes Ithaca and runs south a few miles and thence southwest to the bank of the Grand River channel at Maple Rapids. (See fig. 1, p. 258.) It is a strong, even, continuous ridge. The first ridge (in double form) east of Maple Rapids appears to be part of the Flint moraine. But just east of this, in the northeast part of sec. 2, T. 8 N., R. 3 W. (Essex Township), another moraine, extremely broken and bearing a number of kames and other irregularities, sets in and runs east past Union Home and Eureka. The north face of this moraine is a high, steep bluff, evidently cut away since the moraine was made. Lake beaches along its base may account for part of the cutting but not for the most of it. (See p. 258.)

On the north side of the river the Owosso moraine bends southwestward into the head of the channel and near Maple Rapids virtually forms its north bank. On the south side the trend of the moraine is also westward to the head of the channel. (See fig. 1.) Taken together these two moraines seem to mark the sides of a sharp ice tongue which projected westward to the head of the channel and down it through and beyond the Flint moraine. The cause of this relation will be discussed in connection with drainage (pp. 257–259).

From near the township line 2 miles southeast of Eureka eastward to about 2 miles east of Elsie there was either no morainic deposition or else the moraine was afterward washed away. Beyond this gap the moraine runs southeast as a more continuous and even ridge, passing just north of the cities of Owosso and Corunna and 4 or 5 miles north of Durand. Farther east, toward Flint River, it turns a little north of east and grows much fainter.

If the Flint moraine finds its continuation in the Otisville moraine, then it would seem almost certain that the moraine running north from Flint to Mount Morris is a continuation of the Owosso moraine. Otherwise the Owosso is probably continued in one of the ridges passing just north of Mount Morris and south of Millington.

HENDERSON MORAINE.

The confusion among the slender moraines about the head of the Grand River channel makes it difficult to identify the members. A mile or two northeast of Maple Rapids the channel begins to open out into the basin of Saginaw Bay. The divide between Maple River, which flows west through the Grand River channel, and a branch of Bad River, which flows northeast to Saginaw Bay, is about 1½ miles northeast of Bannister and about 14 miles east of Maple Rapids. West of this divide much of the lake floor approaching the head of the Grand River channel is thickly strewn with bowlders. In a few places fairly distinct belts occur, one of which runs southeast on the divide east of Bannister and is continued in a distinct morainic ridge, known as the Henderson moraine, which begins about a mile south of Chapin and runs southeast, passing about a mile south of Henderson. Southwest of Chapin three smaller ridges lie between the Henderson

and Owosso moraines. From Henderson the Henderson moraine runs eastward to the west bank of Flint River, about 2 miles northwest of Flushing, but it is very faint in this interval and has not been traced continuously. East of the river at Flushing a faint moraine runs south, apparently marking a short, sharp tongue projecting up the river. This moraine is probably represented by one or both of the narrow ridges which pass just north of Mount Morris; it is quite distinct through T. 9 N., R. 7 E. (Thetford Township), and passes 1½ miles south of Millington.

WEST HAVEN MORAINE.

A bowldery belt on the old lake bottom about a mile north of Chapin is probably to be identified with another moraine, which, however, is perhaps not land-laid in this part of the Saginaw Valley. It is not entirely clear whether this moraine, which has been called the West Haven moraine, is a separate individual passing a little south of Oakley, a mile or so northeast of West Haven and a little south of New Lathrop, or whether it belongs to the moraine next mentioned below. Faint indications of such an individual exist 2 miles northeast of West Haven, and regularity of space interval seems to call for it, but it was not identified further.

CHESANING MORAINE.

A very bowldery belt south and west of Laytons Corners marks the course of another moraine, known as the Chesaning. It extends in all about 8 miles or to Shiawassee River south of Chesaning. This belt is slightly below former lake level (10 to 25 feet) and is in the surf-wasted zone of the Arkona beaches, which are the strongest in this part of the Saginaw Basin. Wave work has removed the fine material and left the ground very stony but has not destroyed the morainic knolls, which though low are well defined. The moraine was water-laid, but the water was shallow. This fragment stands alone and was not traced in either direction; it may, however, be continued east of Flint River in the ridge upon which the Arkona beaches rest between Clio and Millington, but this correlation is not certain.

MORAINE NORTH OF CHESANING.

Another faint bowldery tract 2 miles northwest of Chesaning appears by its altitude and general relations to belong to another later moraine, which, however, was not certainly identified elsewhere.

OVERLAPPING OF THE EARLIER MORAINES OF THE DEPLOYED GROUP.

The morainic features in the tier of townships east of Lansing are extremely irregular, the later moraines appearing successively to override the earlier ones. The Lansing, Grand Ledge, and Ionia moraines appear to be involved in the overlapping as far as northeastern Livingston County.

If the Lansing moraine turns southeast from Alverson (see p. 239), it seems probable that it includes the morainic fragments at least as far east as northern Livingston County and that in this interval it overrides earlier morainic deposits. On the the other hand, if the Lansing moraine is overridden east of Alverson by a later moraine, then the fragments may belong to this next later (Grand Ledge) moraine. The morainic deposits are so cut up by transverse troughs and their trends vary so much that it is scarcely possible to identify individuals continuously. But to whichever moraine the fragments in northern Livingston County belong, they appear to be overridden there and eastward by a still later moraine. In fact, though the morainic jumble into which the first three moraines of the deployed group disappear may be partly due to irregularities in the rock surface beneath the drift, it seems to be due chiefly to marginal overriding or overlapping.

The Grand Ledge moraine enters the broken belt north of Lansing; the Ionia moraine enters farther to the east, in the southwest corner of Shiawassee County; the Portland moraine enters near the southwest corner of Genesee County. From here the broken belt extends eastward

into northwestern Oakland County, and, although narrower than at points farther west, it seems to include the Ionia and Portland moraines.

On entering Lapeer County the Portland moraine seems to stand out clearly as the front moraine of the deployed group, although on the meridian of Lansing it is the fourth. This relation, however, is not altogether certain, for it is possible that one or more of the earlier moraines of the group not yet identified emerges from under the later moraines and runs along the face of the higher ground to the south.

In northwestern Livingston County, 5 miles north of Howell, a crescent-shaped morainic loop, the identity and relations of which have not been certainly made out, projects southward about 4 miles beyond the general front of the deployed group. This loop may be a part of the Lansing moraine which was not overridden at this point or it may be still older; it has some characters unlike those of the slender moraines of the deployed group. It is not high, but it is more hummocky and more bowldery, being in these respects more like the massive moraines of the Charlotte system to the south. Its relation to the ice-border drainage also suggests that it is alien to the deployed group; it is cut off along its northern side by a large river channel which comes out of Lapeer County and runs southwest close along the front of the overridden belt to Fowlerville, in northwestern Livingston County.

East of Grand Blanc, in eastern Genesee and western Lapeer counties (Davison, Atlas, Elba, and Hadley townships), the relations of the moraines are very simple. The Fowler moraine is the first which can be traced into Lapeer County continuously and without uncertainty as to its identity. In this stretch the Fowler and two earlier moraines are deployed in open parallel lines and seem to stand in simple consecutive order. If this is the true relation then one running past Elba, which stands next east of the Fowler moraine, may be regarded as the Lyons moraine, and the next which runs past Hadley as the Portland moraine. There is, however, a possibility that the relations are not so simple as they seem, for at Goodrich some high morainic knolls which seem to stand apart from the front of the ridge which passes Elba on the west are probably related to a glacial drainage line which issues from the moraine that runs past Hadley and which passes about 1½ miles southeast of Elba. But it is also possible that the knolls are projecting points of a moraine which was overridden by the later of these ridges; other knolls in Lapeer County stand 2 miles or more southeast of Elba between these ridges. This alternative, though possible, is improbable, for elsewhere overlapping produces a jumbled, confused morainic topography and not an extremely simple one like that here formed.

TOPOGRAPHY.

ALTITUDE.

From the apex of the lobe near Lake Odessa to the west line of Lapeer County is a distance of 80 to 90 miles. If the deployed moraines marked the side of a simple lobe the range in altitude on each individual moraine from the apex to Lapeer County would probably be considerable. But the valley of Flint River caused the formation in Genesee County of a broad subsidiary or side lobe which bulged out toward the southeast, and this tended to lower the moraines slightly in the eastern part of the district. For so great a distance the range in altitude is relatively small, being due partly to the Flint sublobe and partly to the fact that the Saginaw lobe here deployed on a nearly flat plain.

All the moraines rise, though not uniformly, from the apex of the lobe to the west line of Lapeer County. Their lowest parts are all at or near the apex of the lobe, and their highest parts are in the northwest corner of Oakland County and near the northeast corner of Genesee County. In northwestern Oakland County several knobs rise 1,000 feet or more above sea level. All of these appear to belong to the front of the deployed group in the belt of overriding, but may really be slightly earlier with the front of the deployed group laid up against their lower slopes. The general altitude of the morainic knolls in the same area is about 950 feet.

The altitudes given below for the general crest level of the moraines are based on scattered measurements, mostly by aneroid barometer, and are not those of the highest knobs. The values stated are therefore not precise but rather general in quality.

Altitudes on moraines of deployed belt.

Moraine.	Apex.	West line of Lapeer County.	Rise.
	Feet.	*Feet.*	*Feet.*
Lansing	[a] 875	950?	?
Grand Ledge	[a] 880	950?	?
Ionia	[a] 870	950-1000?	?
Portland	820	950	130
Lyons	740	890	150
Fowler	740	870	130
St. Johns	730	850	120
Flint	740	890	150
Owosso	740	860	120
Henderson	730 [b] 680	?	?
West Haven	720 [b] 680	?	?
Chesaning	[b] 680	?	?

[a] Overridden east of Lansing. [b] Water-laid.

Water-laid moraines in general have somewhat less relief than land-laid forms. Some of them may also have been more or less reduced in altitude by wave erosion. The uncertainty of their identity east of Flint River gives no chance for certain determination of their altitudes at the meridian of the west line of Lapeer County nor of the amount of rise. The confusion of the overridden moraines east of Lansing also leaves in doubt the altitude and amount of rise of the individuals in that area.

The altitude of the moraines along the axial line through the successive positions of the apex are of course dependent mainly on the character of the ground over which the ice lobe advanced. From 875 or 880 feet altitude at the apexes on the Lansing and Grand Ledge moraines the altitude drops about 200 feet to the Chesaning moraine, but the greater part of the drop is in the later water-laid moraines which pass below the former lake level. The lower relief of the moraines deposited at the edge of the ice where it stood in lake water contributes something to this difference. A north-and-south line through Owosso crosses all the moraines except the Lansing. The distance is shorter than on the axis and the difference of altitude is a little greater, for the general level of the overriding moraine 5 miles east of Lansing is a little above 900 feet.

The axis of the Flint Valley protrusion was about on a line running northwest and southeast through the city of Flint, and the altitude of two or three of the moraines preceding the Flint is slightly lower near this axis than to the southwest or the northeast. The St. Johns moraine, for example, has a general crest altitude of 875 to 880 feet in the northern part of T. 5 N., R. 5 E. (Argentine Township), and of only about 780 feet in the northwestern part of T. 7 N., R. 8 E. (Davison Township). A lake stood in front of the ice at this stage with its outlet 3 miles north of Linden at an altitude of about 850 feet. Then from the relatively low axis of the Flint sublobe all the moraines rise toward the high morainic area of southern Tuscola County. North of Otter Lake an altitude of over 900 feet is reached on the Otisville moraine.

RELIEF.

The relief of the moraines of this group is generally low, averaging about 20 feet above the plain in front of them and generally somewhat less above that behind them. Their relief, however, in much of their course is considerably less than this, and in some intervals, as from Riley eastward in Clinton County and in southern Gratiot County, it is entirely absent. The water-laid fragments are mostly without noticeable relief.

Where the moraines are developed as distinct individuals without overlapping no point was found with a height of more than 60 feet above the plain and few points above 45 or 50 feet.

In the region of overriding the relief becomes greater, in not a few places reaching 80 or 90 feet, and in some reaching more than 100 feet. This applies especially to the belt east of

Lansing and to the Otisville and other moraines in northeastern Genesee County. The normal relief of these moraines, however, is distinctly lower than that of the bulkier moraines and becomes greater only where several ridges are heaped up together.

CHARACTER.

Where they are openly deployed, these moraines are generally smoother than the bulkier moraines and show fewer knobs and basins and other irregular surface features. They show comparatively little evidence of drainage issuing from the ice while they were making, and perhaps on this account their crests are less broken and irregular. The general flatness of the plain on which they were deposited is probably the principal cause of their comparatively even trend and broad curvature.

In the region of overriding many of the forms developed are remarkably irregular and some of them are almost fantastic. Such forms appear at several places east of Lansing, northeast of Otisville, and particularly in the moraine-rimmed circular basin near Duplain.

STRUCTURE OF THE DRIFT.

THICKNESS.

Throughout most of this district the thickness of the drift averages about 100 feet, but varies locally from practically nothing to 300 or 400 feet. (See Pl. II, in pocket.) Near Grand Ledge in northeastern Eaton County, and through northern Ingham County into northwestern Livingston and southern Shiawassee counties, the drift is in many places thin and in some is interrupted by outcrops of bedrock. Bedrock is also exposed in the Grand River channel about 3 miles east of Ionia. But in general the drift in Ionia, Clinton, Shiawassee, and Genesee counties is 100 to 150 feet in depth, and in the counties which border these on the north it is still deeper. A bored well at Saranac, 8 miles west of Ionia, goes 247 feet to rock, which is there but little more than 400 feet above sea level. This well seems to penetrate an old valley in the rock surface which opens to the northwest and is 150 to 200 feet deep. The present surface of the country, however, gives not the slightest evidence of such a depression in the rock.

COMPOSITION.

In its composition the drift of the district is mostly rather uniform on the visible surface but varies considerably as revealed in deep sections and in well borings. For a depth, say, of 40 to 50 feet, the drift is predominantly clayey with a yellowish or buff color and in places with a tinge of brown. The deployed moraines are composed mainly of this clay. They carry comparatively few bowlders and are notably stony only in some parts of the district of overriding or where they were washed by lake waves.

On the high ground bordering the Grand River channel many sections in the bank and many well borings reveal a thick bed of sand or gravel beneath 50 to 100 feet of till. Both east and west of Ionia the north bank about 85 feet above the valley floor contains a great mass of gravel, though in the town tough clay occurs at that level. Many borings in other parts of the district reveal beds of sand or gravel beneath the surface till or intercalated between beds of till. In the district east of Lansing most of the bored wells get water which contains enough petroleum to give distinct odor and taste.

Many of the borings penetrate in the deeper parts a bed of "hardpan," or dark-colored indurated till, generally very stony, from a few feet to 80 or 100 feet thick, and commonly separated from the bedrock by 2 or 3 feet of open, clean gravel in which the best water supply is found. The dark indurated till appears to be distinctly older than the Wisconsin drift. In places it shows cemented ferruginous bands and other evidences that suggest weathering. But the "hardpan" is not so thick in this district as it is in some of the neighboring counties east and west.

The percentage of crystalline material from Canadian sources is relatively small in the surface parts of the drift, probably more than 90 per cent of the general drift mass being derived from the Paleozoic rocks, mostly from near-by sources.

In several places, as below the asylum southwest of Ionia and at the brickyards 2 miles east of Lansing, pebbleless clays, evidently deposited in lake waters, appear to have been overridden by later ice advances. Those near Ionia are deeply buried under till. Those east of Lansing are overlain by thin, patchy till with bowlders. It seems probable that the lake waters in which these clays were deposited were temporary local bodies of relatively small extent.

ASSOCIATED TILL PLAINS.

The deployed slender moraines lie in roughly parallel lines, except in the region of overlapping east of Lansing, and the intervals between them vary from 1 to 6 miles in width. The till plains which lie between the moraines are long narrow strips of irregular width and are generally typical of their kind. They are plains of clay, more or less pebbly and stony, and have generally a smooth surface which, although flat and apparently level, is nearly everywhere slightly inclined in one direction or another.

The inclination of the till plains depends chiefly on the general slope of the region. Under normal conditions of deposition in a flat region the terminal moraines are heaped up in ridges and the till plains slope gently backward from them in the direction in which the ice retreated. The surface of each till plain is therefore normally highest at the inner edge of the moraine with which it is associated and lowest immediately in front of the next succeeding moraine. The terminal moraine is a heaped-up marginal deposit of till, and the till plain or ground moraine is a subglacial formation spread in a smooth and relatively thin sheet under the weight of the moving ice. The till plains are composed mainly of bowlder clay, but they have few bowlders on their surface or in the sections that show their structure.

The till plain in front of the Lansing moraine slopes gently southward. This plain belongs to the heavier morainic belt (Charlotte morainic system) south of the deployed group.

The till plain on the inside of the Lansing moraine has no well-defined general direction of slope but is inclined slightly in different directions in different parts. The remainder of the till plains back to the shores of glacial Lake Saginaw all slope gently back from the moraines with which they are associated, except in a few localities, such as south of St. Johns, where the plain slopes south and thus guided a glacial river through a gap in the Fowler moraine. After passing through this moraine, the river crossed the next till plain inside the Lyons moraine instead of going northwestward to the Grand River channel south of Matherton. For 10 miles west of Bancroft the Lookingglass glacial river flowed in the till plain of the Lyons moraine, most of the way close back of the moraine rather than farther north.

The till plains are all essentially the same in the remainder of the district back to the beaches of glacial Lake Saginaw. In the eastern part of Genesee County the shallow basins across which the moraines were built led to the formation of shallow glacial lakes like Davison and Kersley (pp. 252, 254), where the till plain dipped to a lower level along a part of its length.

Below the Arkona beaches the slender moraines are water-laid and on that account present little or no contrast with the till plains; and further, they were nearly leveled by the severe wave erosion.

The whole region below the Arkona beaches is a plain without prominent features, the higher parts carrying scattered bowldery patches marking the remains of moraines. The lower part outside of the Port Huron morainic system and comprising the central part of Saginaw County is a plain of faintly laminated lake clays, containing few pebbles or coarse material. In texture they are waxy and apparently as fine grained as cocoa butter. Shafts sunk for coal mining have passed through these clays at a number of places, one at St. Charles penetrating them to a depth of 90 feet.

ESKERS.

BURIED MASON ESKER.

The Mason esker attains its best development in the region south of this district, and that part is described by Mr. Leverett. (See Pl. VIII, p. 208.) It reappears in full strength on the north side of Cedar River in the southeast part of Lansing. A short distance north of the river it appears to be overridden and partly buried under till. Both north and south of Michigan Avenue the troughs on its sides are filled with till and its gravel ridge is nearly level with the general surface. About a mile farther north, at Sheridan Street, it reappears in normal relations as a gravel ridge 20 to 30 feet high and 100 to 200 feet wide, with swampy troughs on both sides. About a mile to the north it heads in two or three short branches.

On both sides of Michigan Avenue, where the esker troughs are filled with drift, large pits were opened many years ago for gravel and sand. Most of the pit walls were old and covered with talus at the time of the writer's visit, so that no good sections showing the structure of the deeper parts were found. Sand is a large component throughout, but considerable coarse material is present in the upper layers, and several crystalline bowlders and two or three large blocks of much disintegrated bituminous coal were seen. The largest coal bowlders were 2 feet or more in diameter and many smaller pieces occurred in the upper layers. The deeper parts, so far as shown, appeared to consist of horizontally bedded sand of about the grade used for making mortar. The upper layers were not so distinctly bedded.

The front of the Lansing moraine runs toward the northeast through secs. 30 and 20, Lansing Township, crosses to the north side of Grand River at the Logan Street Bridge, and runs thence east through the southern part of the city, crossing the river again just below the junction of Cedar River. West of the bridge it occupies both sides of the river, but in the city it is not very strongly developed. It is somewhat stronger on the east side of the river between the river and the esker. The trend of the moraine to this point carries it directly to the overridden part of the Mason esker and it seems certain that it was the Lansing moraine that overrode the esker ridge and filled the troughs on its sides.

East of the buried section of the Mason esker a small flat plain about half a mile wide forms a recess between the esker and a high morainic ridge to the northeast. This seems like a till plain, but it originally carried many bowlders. The unmodified part of the esker, with its lateral troughs running north from Sheridan Street, was probably formed at the time of the Lansing moraine, for it shows no effects of overriding. It seems probable, therefore, that the ice front rested on the flat plain east of the esker but deposited only bowlders at that place.

Beds of laminated brick clays lie on both sides of Michigan Avenue, about 3 miles east of the State capitol. On the north side, the clays are about 10 feet deep and though they appear to contain no stones, they are contiguous to stony ground that suggests a thin overlying layer of till. The time and circumstances of the deposition of this small body of lake clays were not definitely determined, but probably they were laid down in a local lake formed south and east of Lansing by an obstruction of the Lansing channel southwest of the city. (See p. 251.) If, however, they are buried under stony till it is not clear whether the overriding was done by the Lansing or by the Grand Ledge moraine, for the high moraine just back of the clays to the northeast appears to belong to the Grand Ledge moraine rather than to the Lansing.

The Mason esker seems to end in the southeast part of sec. 3, Lansing Township, and it does not reappear farther north except in a few small fragments. The trough, however, which runs northward in well-defined form as a swampy depression from sec. 34 to sec. 4, Dewitt Township, contains several small knolls or ridges of gravel. North of Dewitt, in Olive Township, an esker nearly a mile long, belonging to the time of the Portland moraine, runs north to south in secs. 26 and 35. Thence northward the line of the esker is not continued by a definite trough but is represented by a series of separate swamps lying between the morainic ridges and trending a little east of north.

THREAD RIVER ESKER.

A large and rather irregular esker about 5 miles long, known as the Thread River esker runs southeast from Flint. Its south part lies half a mile or more south of the front of the St. Johns moraine and was therefore formed in connection with the Fowler moraine. Thread River flows in the west side of its trough for a mile or two. Its passage through the St. Johns moraine in sec. 33, T. 7 N., R. 7 E., is typical, the esker being interrupted and terminated on the north side of the break by two large kames. The large kettle hole in the south part of Flint is probably related to the esker trough, although it shows no direct connection.

This esker was made by a subglacial river flowing southeastward along the axis of the Flint protrusion or lateral lobe. Near Flint the esker is worked extensively for gravel for the manufacture of cement blocks and sand-lime bricks; it shows a percentage of gravel larger than that of most eskers in this region.

THETFORD ESKER.

The Thetford esker, which runs south through secs. 5, 8, and 17 in Thetford Township, in northern Genesee County, is a sharp-topped, well-formed ridge, apparently related to the Owosso moraine. In the south part of sec. 8 it has a sharp jog to the east. Two or three small kames stand east of its south end.

MISCELLANEOUS SMALL ESKERS.

There are in this district a few other eskers a mile or so in length and a considerable number of shorter ones. One of the most notable lies east of Ovid. The trough which contains it comes from the northeast. In sec. 6, Owosso Township, and sec. 12, Middlebury Township, the trough contains a fine and conspicuous fragment of esker more than half a mile long. Farther west, in sec. 12, Middlebury Township, it contains another esker about three-fourths of a mile long, nearly parallel to the front of the Flint moraine. After cutting nearly through the moraine, the trough runs for some distance nearly parallel with the Imlay channel but finally enters it from the east, pointing downstream, as if influenced by the direction of flow of the Imlay outlet river, though how this could have occurred is not clear.

The east side of the large trough which runs southwest from Owosso through the Flint moraine contains two fragments of eskers. A little farther south and across the Imlay channel three esker-like gravel ridges cut through the St. Johns moraine, two of them running on to the Fowler moraine, 2 miles to the south. A well-formed gravelly esker over half a mile long runs southwest through the Flint moraine in sec. 31, Clayton Township, Genesee County.

A small, low esker about a mile long runs southeast past the road corners a mile north of Davison, in Genesee County. Several small eskers occur in relation to the expanded part of the St. Johns moraine and also in relation to the Fowler moraine in southwestern Genesee County.

In central Clinton County a number of kames are associated with the irregular moraines. One situated 2 miles northwest of St. Johns is somewhat like an esker, being drawn out to a length of over 2 miles toward the southwest, but is so broad and flat that it seems like a kame rather than an esker.

GLACIAL DRAINAGE.

GENERAL FEATURES.

The drainage associated with the ice border presents considerable variety. During some of the earlier positions of the ice in the western part of the district, the drainage flowed in relatively small channels directly away from the front. At other times it collected in rivers of greater or less size.

The rivers which flowed along the front of the ice are of two types—those that gathered their waters from the ice and land of the immediate vicinity or from areas not far away and those that were the outlets of one or more of the greater glacial lakes. Most of the former class have relatively small and shallow channels, indicating relatively small volume and short duration. Those of the latter are generally much larger and more deeply intrenched, showing

large volume and in some parts suggesting longer duration. Of the former class are the Holly, which is the largest, the Lookingglass, the Bennington, and the Butternut channels. Of the latter class are the Imlay channel, with several branches in its western part, and the Grand River channel, which is of truly great capacity and relatively mature development.

Besides these in which the connections and relations are clear, there are one or two fragments of channels which are isolated and the connections of which are problematic. Of this class is the Lansing channel, which is as large or larger than the Holly channel.

While the ice front was retreating across this district and building the slender moraines of the deployed group the amount of sandy and gravelly outwash shed from the front of the ice or brought out by streams issuing from it was relatively small; indeed, in comparison with that which issued from the front of some of the bulkier moraines, it seems extremely small. This, perhaps, is due to a lack of concentration; if all the slender moraines were compacted into one mass and all the outwash concentrated on one line the discrepance might not seem so great.

DRAINAGE SOUTH OF IMLAY CHANNEL.

DISTRIBUTION.

During the formation of the Lansing moraine all the drainage along its front west of Lansing appears to have been directly away from the ice, mainly along the courses of several creeks which flowed southwest. The valleys of the creeks show in some places gravelly terraces or remnants of valley gravels that seem to belong to the time when the ice was present. The creeks occur at intervals of 3 to 4 miles, and most of them, such as Sebewa Creek, Mud Creek, and three or four branches of Coldwater Creek seem to have issued directly from the ice. Streams appear to have issued along the same lines during the building of the Grand Ledge moraine. As a result, they begin at the Grand Ledge moraine and run southwestward directly through the Lansing moraine.

LANSING CHANNEL.

Along most of its front the Lansing moraine shows no evidence of concentrated drainage or of readvance of the ice, but at Lansing it furnishes a striking example of readvance, closing a large channel of ice-border drainage which had been made just before, when the ice front stood a little farther to the north. From the vicinity of East Lansing, a flat valley one-half to three-fourths mile broad, distinctly depressed below the surrounding till plain and floored with sand and gravel, extends westward to the south part of Lansing and on for about 1½ miles up Grand River to the Logan Street Bridge. This part of the old drainage channel was not overridden at the time of the Lansing moraine. In this old channel Cedar River wanders in many meanders, generally with a sluggish current, and Grand River has wide room to spare. But at the Logan Street Bridge Grand River is suddenly shut in between walls of bowlder clay 30 to 40 feet high and the channel is so narrow that it has no well-defined flood plain. A dam a quarter of a mile below now backs the water up into the narrow part. The banks are steep and the topography of the drift on both sides of the river for about 3 miles to the southwest is distinctly morainic and is in fact a part of the Lansing moraine. The old drainage channel was evidently overridden and completely filled up for some distance west of Lansing.

A large channel of glacial drainage runs northwest from the bend of Grand River at Diamondale, as shown on the Lansing topographic sheet, and expands into a swamp close in front of the Lansing moraine. The Diamondale channel turns a right angle in this swamp and passes westward down Thornapple River. It may be that the buried Lansing channel formerly extended westward and joined the Thornapple channel at this place in the southwest corner of T. 4 N., R. 3 W. (Delta Township). The features suggest this relation, but no certain proof was found.

East of East Lansing the old channel seems to branch, one part coming down Cedar River from Okemos and the other from Pine Lake across the northwestern part of T. 4 N., R. 1 W. (Meridian Township). This is well within the region of the overlapping moraines, where the relations are complicated. The drainage along the front of this belt will be described later (p. 253).

While the Grand Ledge moraine was building, conditions along the ice front west of Lansing were about the same as at the preceding halt. A few small gravel terraces in Grand Ledge and Lansing and between these places seem to belong to temporary drainage during the building of this moraine, but they are small and fragmentary. The conditions remained the same during the building of the Ionia moraine. There is scarcely any outwash directly from the ice front along any of the three moraines between Lansing and the Grand River channel.

LOOKINGGLASS CHANNEL.

During the building of the next or Portland moraine the outwash directly from the ice in the interval between the Grand River channel and the region of overlapping was as small as it was during the construction of the earlier moraines. However, a river of moderate size flowed along the front of this moraine from Dewitt, following the course of Lookingglass River westward to Portland, thence going northwest for 3 or 4 miles on the present course of Grand River and thence by a cut-off past Collins close against the front of the moraine to the Grand River channel. Its course is well marked by gravelly terraces and a widened valley 20 to 40 feet above the flood plains of the rivers. This stream appears to have continued in the same course west of Dewitt during the making of the next two moraines. It probably abandoned the short cut-off past Collins, 5 miles northwest of Portland, as soon as the ice retreated from the Portland moraine, and thereafter it followed the present course of Grand River to Lyons. As the ice front retreated, the headward parts of this stream fell backward, cutting through successively later moraines, but the stream was unable to find a course westward along their fronts and so continued to follow the Lookingglass River from a point near Bancroft. During the building of the Fowler moraine the headward parts came from northwestern Lapeer County to the headwaters of Shiawassee River east of Linden and thence down this stream to the Lookingglass south of Bancroft. When the ice retreated to the St. Johns moraine, the drainage reached back along the front of that moraine to the outlet of the Davison glacial lake about 3 miles north of Linden. This lake filled a long, narrow trough in front of the St. Johns moraine, extending northeast at least as far as the north side of Davison Township, Genesee County, and received tributaries from the northern part of Lapeer County.

BENNINGTON CHANNEL.

This last arrangement, however, was short lived, for the river soon found a new course. Instead of following the Lookingglass west of Bancroft, it continued northwestward along the front of the St. Johns moraine to a point 3 miles southeast of St. Johns. Here it left the St. Johns moraine, and after cutting through the Fowler moraine continued westward to the Grand River channel 2 miles above Lyons. The new course from Bancroft west is known as the Bennington channel. This channel is not large, but is particularly well developed west of Bennington, from which it takes its name. At Bennington it appears to be partly choked with gravels brought into it by three streams, which issued from the ice 2 to 5 miles to the east. During the building of the Fowler and St. Johns moraines the eastern part of this stream flowed along the north or inner side of the belt of overlapping moraines which extends eastward from Lansing.

HOLLY CHANNEL.

During the building of the ridge that passes west of Hadley (probably the eastward extension of the Portland moraine) there was in central Lapeer County a glacial lake which had its outlet southwestward along the front of this ridge. In the southwest part of Hadley Township the old bed of this river is prominent, having a flat, swampy floor one-fourth to one-half mile wide. It was first noted near Holly in Oakland County and called the Holly glacial river and its bed the Holly channel. From the southwest corner of Lapeer County the Holly channel runs south-southwest through Groveland and Holly townships, in northern Oakland County (T. 5 N., Rs. 8 and 7 E.), and Tyrone, Deerfield, Cohoctah, and Conway townships, Livingston County (T. 4 N., Rs. 6, 5, 4, and 3 E.), to a point on Cedar River 2 miles northwest of Fowler-

ville, a distance of about 45 miles from its head near Hadley. It is particularly well developed in Holly Township. Its course is mostly through a jumbled, broken morainic country, some of which has moderately strong relief. Through this the river wound deviously, in places through narrow passages between high hills, as in the eastern and western parts of Holly Township, and in places over broad flats where it laid down extensive deposits of gravel and sand, as in central Holly and central Deerfield townships. Its character and continuity are unbroken to the point near Fowlerville and it has evidently not been overridden by a later readvance of the ice east of there. Its relation to the general slope of the country, which declines toward the northwest, and to a number of streams which flow in that direction across it and through some of the moraines north of it, establish its relation to the ice front very clearly.

Kersley Creek, for instance, rises in the high morainic hills south and east of Ortonville, flows northwest across the Holly channel, through the Hadley ridge and three other moraines and across the drainage channels or lake beds in front of them, and finally reaches Flint River 3 miles north of Flint. Another branch of the same stream crosses the channel and the Hadley ridge in western Groveland Township and joins the main creek near Goodrich. In Tyrone, Deerfield, and eastern Cohoctah townships several of the headward branches of Shiawassee River flow northward across the Holly channel and through the moraines to the main river, which follows the course of glacial drainage westward along the front of the Fowler moraine. East of Cohoctah Township the belt of jumbled moraines extends about to Goodrich and is only 3 or 4 miles wide, being bounded on the north by the drainage channel along the front of the Fowler moraine and on the south by the Holly channel.

Some channels of glacial rivers throw a more certain light on contemporary positions of the ice front than do the moraines, especially where the course and continuity of the latter are doubtful. It seems entirely certain, for instance, that when Holly River was flowing the ice front rested close along its north side, at least from Lapeer County to the north-central part of Livingston County, for if the ice had stood farther toward the south the site of the channel would have been buried under ice, and if it had stood much farther north the river would have turned in that direction along the course of some of the creeks that cross it and would have escaped westward on a lower and more northerly line.

The fragment of old channel at Lansing may be a continuation of the Holly channel, which it resembles closely, especially as the Cedar Valley seems a natural course westward from Fowlerville. The Lansing channel was closed, as described above, by a readvance of the ice front to the Lansing moraine, but the Holly channel in Lapeer County runs along the front of the Hadley ridge, which seems to correlate with the Portland or fourth moraine farther west. Hence the Holly channel can hardly be earlier than the Hadley ridge which supported it. For this reason it seems certain that the Lansing channel is not a part of the Holly but is probably a fragment of an earlier channel which has been overridden and obliterated entirely east of Okemos.

The closing of the Lansing channel west of that city by a readvance of the ice to the Lansing moraine indicates a preceding recession of the ice front for at least 2 or 3 miles. But the character of the Lansing channel—its magnitude and relative strength of development—coupled with the fact that it seems to be entirely overridden in the eastern part of the area, are still more significant in their bearing on conditions immediately preceding the building of the Lansing moraine. The size of this channel indicates a large river, as large or larger than the Holly. Its source must have been as far back as Lapeer County, where the Holly channel gathered most of its waters, and the Lansing fragment lies only a little lower. It looks like an earlier drainage line of which the Holly is a later revival on a slightly different course. Lansing River probably drained substantially the same area, but its course, not far north of the Holly, has been overridden and obliterated. It evidently marks a somewhat longer interval of time than that which separated the successive slender moraines of the deployed group, and it indicates a greater readvance than that which closed a few miles of the channel west of Lansing.

The fixing of the time of the Holly glacial river as coincident with the formation of the Hadley ridge raises the question as to whether some or all of the slender moraines earlier than the Hadley ridge or Portland moraine may not be present south of the Holly channel. But no

evidence favoring this interpretation was found. When the ice front rested on the high moraine east and south of Ortonville it had free drainage southeastward into the interlobate area of that time at a level over 200 feet higher than the Holly channel just north, and no certain evidence of later moraines nor of ice-border drainage was found on the slope down to the channel. If the ice front paused in its retreat down this slope, it made no distinct moraines and left no trace of ice-border drainage. The absence of drainage channels, however, is not by itself conclusive, because the interlobate area in Lapeer County may have drained southward along the east side of the "thumb" during this time, and Holly River may have been the first diversion of that drainage to the west side.

On the other hand, if the slender moraines of this group mark a pronounced readvance of the ice front, as is perhaps suggested by the buried Lansing channel, the first diversion of drainage to the west side may have been along a line farther north than the Holly channel (pp. 252–253), and the channel made then may have been overridden. The drainage line may then have been pushed up the slope to the position of the Holly channel by a readvance to the Hadley ridge.

ELBA CHANNEL.

During the building of the Lyons moraine, which is next later than the Portland, drainage from Lapeer County passed southwestward along the front of the moraine. Its course, however, was not determined, for the moraine disappears in the overridden belt. The drainage may have reached the Holly channel in Groveland or Holly Township.

The amount of outwash from the morainic deposits in the belt of overlapping east of Lansing appears to be small, being limited to a few kames and to gravels and sands deposited in transverse troughs which seem to be in some sense successors of lines of eskers farther south. Along the Holly glacial river and in the lake region near Fenton and Argentine in front of the Fowler moraine considerable areas of gravels and sands are found, but these appear to have been gathered and deposited mainly by the rivers flowing along the ice front.

IMLAY CHANNEL AND KERSLEY GLACIAL LAKE.

When the ice front retreated from the St. Johns moraine a great river suddenly made its appearance and flowed westward close along the front of the Saginaw lobe from a point near Flint to the Grand River channel at Maple Rapids and thence along the course of Maple and Grand rivers to glacial Lake Chicago, which it entered a few miles southwest of the city of Grand Rapids. This river came thus suddenly upon the scene when the retreat of the ice opened a new outlet for the glacial Lake Maumee near Imlay in eastern Lapeer County. The new river was several times larger than any of those previously described in this district, its floor being generally a mile or more in width though somewhat narrower in a few places. From its head to Maple Rapids this old river bed is called the Imlay channel.

When the river first began to flow, the ice front was resting on the Flint moraine, or probably on a line a little farther north that was overridden by a readvance of the ice, but it kept its course along the front of the Flint moraine westward from Flint to a point southwest of Owosso only while the ice rested on that moraine. When the ice front drew back to the Owosso moraine the outlet river broke through the Flint moraine at Flint and followed the front of the Owosso moraine on a line farther north. The channel which it made in this new position, however, is not so deeply trenched nor so well defined, apparently because the fall of the stream and velocity of current were less west of Flint than they were when the ice rested on the Flint moraine. It is, however, fairly well defined from a point north of Vernon westward past Corunna to Owosso. The depression continues past Elsie but shows less evidence of scour west of Owosso.

Running through the Flint moraine southwest from Owosso there is a broad, flat transverse valley containing fragments of an esker on its east side. During the development of the Flint moraine this was an esker trough, probably marking a strong line of drainage issuing from the ice. The Michigan Central Railroad passes through it. That part of the Imlay channel which runs west from this trough to Maple Rapids is generally wider and otherwise suggests somewhat

longer use than the part east toward Flint. The western part may be called the Ovid section and the eastern part the Vernon section. The Vernon section is one-half to two-thirds of a mile wide, and the Ovid section extending west from the Owosso esker trough is fully a mile wide at all points.

The explanation of this difference is perhaps to be found in the Owosso esker trough. During the building of the Owosso moraine a considerable part, though probably not all, of the river turned out of the Owosso channel at Owosso and passed southwest through the esker trough back to the Ovid section of the original channel, thus causing this part of the channel to be used longer and made wider than the Vernon section.

At its first flow the outlet river entered Genesee County through two or three distributary channels passing near Richfield and Davison, and formed a long, narrow lake, extending from Richfield southwestward to the vicinity of Duffield. This may be called Kersley glacial lake, after the principal creek that flows across its bottom. The outlet of this lake appears to have been at first just north of Duffield, but by erosion to have retreated eastward 2 or 3 miles. This is the head of the Vernon section of the outlet channel and it was used only so long as the Kersley glacial lake existed.

With further retreat of the ice the river abandoned the Owosso channel and continued northwest from Flint to Flushing, where it entered early Lake Saginaw. At this time it entered Genesee County northeast of Richfield and flowed thence west past Genesee and Flint to Flushing and appears to have flowed for a considerably longer time in this course than in any of the earlier parts farther west.

The distributaries near Richfield and Davison are very immature river channels and were evidently occupied for only a short time. Northeast of Davison the southern distributary is partly obstructed by three or four drift knolls which were standing as islands in the river when it ceased to flow. They were apparently carved by the stream out of a morainic ridge. A large distributary flowed west through northern Richfield Township and was joined in the western part by another from the north. The northern distributary which flowed westward along the present course of Flint River soon became dominant and determined the later course of the outlet river and the present Flint River. The part of the channel extending from Lapeer County to Flushing is considerably wider and more deeply trenched than the parts west of Flint. It also developed more extensive valley gravels which now form terraces above Flint River.

GRAND RIVER CHANNEL.

GENERAL FEATURES.

The Grand River channel is the largest and most deeply trenched glacial river channel in Michigan and is one of the finest in the glaciated area of North America. The deeply trenched part extends from a mile or more above the village of Maple Rapids to 5 or 6 miles southwest of the city of Grand Rapids, a distance of about 75 miles. By later erosion the head retreated about 16 miles farther east to the swampy divide north of Bannister. The part more particularly described here extends from this divide to Saranac. The floor of the channel is 1 to 1½ miles wide and shows abundant evidence of having been scoured by a great river. Above Lyons, where the modern Grand River enters, the channel is now occupied only by Maple River, a relatively small, sluggish stream which is lost on the swampy floor throughout its whole course from 2 miles northwest of Bannister. The channel floor to Lyons is mostly a very stony, bowldery old river bed, strongly indicating prolonged scour. Some few bars of gravel or sand that rise 10 to 12 feet above the swampy floor are distinctly due to the action of a great westward-flowing river.

In the lower part of its course between Lowell and Grand Rapids the channel is more deeply depressed in the drift than toward its head. At some points its bottom lies more than 200 feet below the country level a mile back, although the bluffs which form the immediate banks are in few places over 120 feet high. Maple Rapids is on a terrace 25 to 30 feet above the channel floor, but the general country level in that vicinity is 50 to 60 feet above the floor. Where the moraines

are cut off at the channel 2 or 3 miles east of Maple Rapids the bluffs are 80 to 90 feet high at some points.

The relations of the slender moraines of the deployed group to the Grand River channel show clearly that practically all of the channel was excavated after the building of the moraines. The gently curving lines which the moraines take in bending around from east and west courses on the meridian of Lansing to north and south courses where they cross the channel show that the floor upon which the ice moved was smooth and without any important depression transverse to its front. All the moraines except the Owosso (pp. 243, 257–259) cross the channel with little or no change in their trend.

EARLY HISTORY.

During the deposition of the early moraines of the deployed group the Grand River channel was a shallow, ill-defined depression in the surface of the drift. But though it was shallow at first, the drainage from the ice and the near-by land gathered into it and soon began to develop a definite river bed. As has been pointed out above, there was no concentration of drainage on the south side of the channel during the deposition of the first three moraines. On the north side there was rather strong drainage along the ice border at all stages of the ice front, but it did not follow the ice front all the way to the line of the Grand River channel during the formation of the earlier moraines. It turned off at points 10 to 20 miles north of Ionia and ran southwest down the course of Dickenson Creek and Flat River to the line of the Grand River channel at Lowell.

On the south side of the channel south of Ionia the plain between the Grand Ledge and Ionia moraines for 1 to 2 miles back from the bluff is covered with a thin coating of gravelly outwash which was evidently deposited before the excavating of the deep channel was begun. Its western part lies in front of the Grand Ledge moraine as this runs northward along the east side of Berlin Township and may be outwash from the ice front at this halt, but its main body forms an apron-like front to the Ionia moraine. From this moraine it slopes westward with decreasing coarseness.

It is possible, however, that this deposit belongs to the Portland moraine and was deposited by a river coming from the north along the course of Prairie Creek. The valley of this creek seems to indicate previous occupation by a larger stream, and there is a small gravel deposit on its east bank north of Grand River. In this case it may be assumed that a large part of the original deposit was cut away by the later making of the Grand River channel.

A small gravel deposit on the brow of the bluff at the north end of the channel which passes Collins was probably deposited by the first flow of the Lookingglass glacial river, which skirted the front of the Portland moraine. Another small deposit in this channel just east of Collins probably marks a late stage of this moraine, when the drainage was first diverted toward Lyons.

No distinct evidence of outwash was observed in connection with the Lyons moraine; drainage from the north at that stage probably continued to follow the course of Prairie Creek. At this stage the Lookingglass glacial river broke through the Portland moraine east of Collins and joined the line of the main channel at Lyons.

During the making of these moraines the channel along the line of drainage westward had been progressively deepening eastward as the ice withdrew, and the advent of the larger volume of the Lookingglass glacial river no doubt augmented this process.

On the south side of the channel at Matherton a very well defined fan of outwash, deposited on the edge of the plain, indicates the absence of any distinct channel there at that time. The drainage which made this deposit appears to have come from the north, but it may have issued directly from the ice.

INCURSION OF THE IMLAY OUTLET RIVER.

Prior to the formation of the great Imlay outlet the volume of drainage gathered along the line of the Grand River channel was relatively small and the channel produced was of correspondingly small magnitude and depth. When the Imlay outlet river first began to flow it entered the line of the Grand River channel just south of Maple Rapids. At that time the outlet river

had a small lakelike expansion just west of Duplain. In the east side of this a large gravel deposit occupies the position of a delta, but seems rather to have been an island-like obstacle in the flow of the river, the current dividing around it with the larger part passing around the north side. It is oval in form and stands 10 to 15 feet above the swamp. Along its west and north sides a prominent gravel ridge runs like a parapet and closely resembles a beach ridge made by waves; from this there is a steep descent into the swamp which stretches away to the west. A narrower channel passes around its south side. This deposit seems more like a kame than any other type—a kame deposited in a small reentrant of the ice front and shaped partly by the ice with which it was in contact and perhaps partly by the later river current. It seems impossible to explain its peculiarities on the supposition that it is simply a delta.

Southeast of Maple Rapids the river appears to have entered a shallow basin and deposited a thin gravelly delta. East of Maple Rapids and resting against the front of the Flint moraine another bed of gravel, much coarser and thicker, appears to have been shed directly from the ice front or else brought in from the east along the eroded bluff. For several miles west of Duplain the Flint moraine is represented by only a few scattered knolls; either it was not formed or else it was washed away by the outlet river. In this interval the channel is nearly all a swamp.

With the advent of the outlet river the increase of volume must have been sudden and great, so that the preexisting river bed along the line of drainage westward was much too small. In its first rush the great river must have torn away the banks of the then existing channel and made a new bed suited to its volume. In doing this it must have swept along a great amount of sediment, and it may possibly have deposited the gravel on the bluff south of Matherton, south of Ionia, and 2 miles west of Lyons in its first rush. The deposit south of Matherton in particular might have had such an origin; the others are thin and flat and appear to have been laid down by small rather than great volumes of water.

RELATION OF THE GRAND RIVER CHANNEL TO THE COURSE OF THE MORAINES.

Early moraines.—As already noted (p. 256), the early moraines show scarcely any tendency to project westward out of their even curves where they cross the Grand River channel. Except in the case of the Lansing moraine at Lansing, no very pronounced evidence of readvance has been found among them; and if the Lansing moraine is the foremost one of a distinct group its readvance may not signify a normal habit for the slender moraines in general but may mark only a readvance after a relatively long backstep in the general glacial retreat.

Owosso moraine.—East of Maple Rapids, however, there seems to be no escape from the conclusion that there was some readvance. The Flint moraine, like all the older moraines of the deployed group, comes up to the Grand River channel on the south side without showing the slightest evidence that any channel or depression was present to influence the movement of the ice, and it seems to pass on to the north with the same general trend. East of the Flint moraine, however, another moraine runs eastward past Union Home and Eureka, forming a high bluff along the south side of Maple River where the head of the Grand River channel widens to the east. (See fig. 1, p. 258.) This fragment is of irregular form and is out of adjustment with the Flint moraine. It runs westward into the head of the channel.

On the north side of the channel a strong, continuous moraine runs south from Ithaca, turning southwestward into the head of the channel, to a point opposite Maple Rapids. (See fig. 1.) This part of the moraine projects westward through the Flint moraine, as though a depression had led the ice to flow a mile or two farther west during the building of the Owosso moraine than it did during the building of the Flint moraine. Such a depression can be accounted for only as the work of the Imlay outlet river immediately before the readvance to the Owosso moraine, and the sharp ice tongue which pushed its point westward to Maple Rapids can hardly be explained except on the supposition that its axis followed a pronounced depression.

The events leading to this result are conceived to have been about as follows: When the ice withdrew from the Flint moraine to some point a little farther east than Eureka, the Imlay outlet river rushed in westward along the front of the ice and cut the channel back several miles

eastward from Maple Rapids. Then on its readvance to the Owosso moraine the ice pushed into the newly extended head of the outlet so as to project a tongue 5 or 6 miles westward beyond the even line of curvature which it would otherwise have had. And further, as it readvanced the ice pressed the outlet river up the slope to the south, until it closed the channel again and forced the river back to its course westward from Duplain. Then, while restored flow by this course was going on, the ice built the moraine from Eureka west. Finally, when the ice receded from this moraine, the outlet river rushed again into the narrow passage along the ice front and cut away a considerable part of the north side of the new moraine. The other part of this moraine,

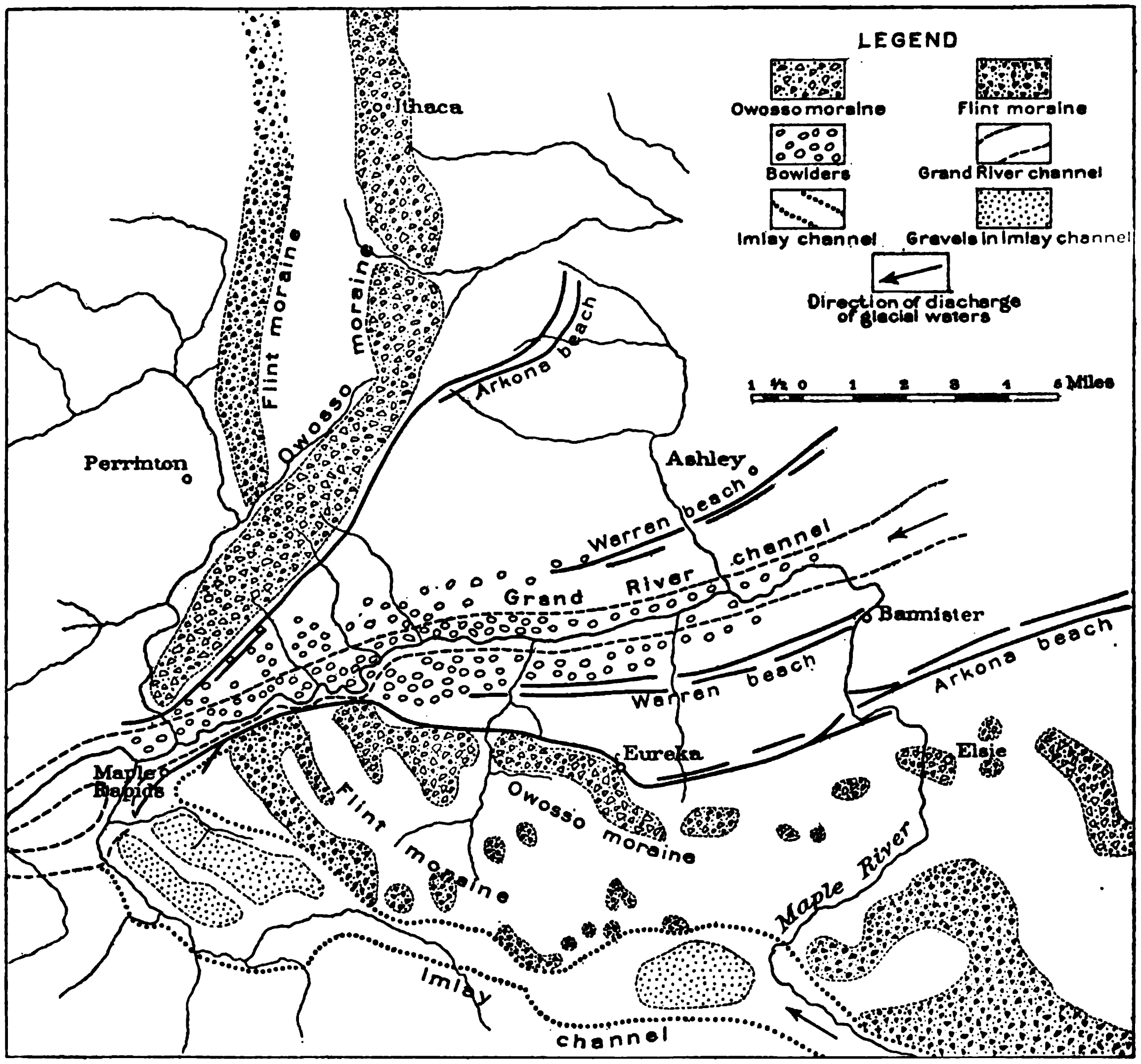

FIGURE 1.—Map showing relation of Flint and Owosso moraines to the Grand River channel.

extending southward from Ithaca into the head of the channel, was not modified in this way, for no river of any size flowed southward between it and the ice.

This rather complicated history seems clearly indicated by the form and relations of the Owosso moraine in this locality. The particular form of discordance seen in this moraine is precisely of that character which requires the supposition of an axial trough or depression for the ice to enter in order to produce the tongue—a depression which was obviously not there when the Flint moraine was made.

Although shore lines exist along the north or back slope of the Owosso moraine, the cutting west of Eureka seems much greater than can be ascribed to waves. For several miles east of

Eureka the moraine seems to be cut away entirely. The part north of Maple Rapids was attacked by waves in the same way but was not comparably eroded. The conclusion seems plain, therefore, that it was the return of the outlet river to a course close in front of the ice, when the ice began to withdraw from the moraine west of Eureka, that caused the heavy cutting along this part.

These facts seem to establish beyond a doubt a movement of readvance to the Owosso moraine amounting to at least 4 or 5 miles, and as no reason can be assigned why there should have been a readvance to the Owosso moraine more than to others of the deployed group, there is a possibility that a similar readvance preceded the building of each one of the slender moraines. If oscillations with moderate readvances like this characterized the whole group the fact is highly important in the discussion of all glacial and climatic questions and theories.

Henderson moraine.—A mile or two east of Bannister a faint bowldery belt having a northwest trend forms the watershed between Saginaw Bay and Lake Michigan. This belt, which apparently marks the course of the Henderson moraine (the next following the Owosso), shows no tendency to bend westward into the Grand River channel. The ice front did not form a tongue like that of the Owosso moraine, for at this stage the moraine lay on flat ground a little east of the head of the channel. That the outlet was not cut back to this position seems certain, from the fact that though the outlet river was active for a relatively long time after the ice had retreated permanently from this vicinity, there is now only a very shallow broad depression on the divide. The original divide was farther west.

TERRACES IN THE GRAND RIVER CHANNEL.

In addition to the relatively small, thin gravel deposits associated with the moraines at the top of the bluff (p. 256), a complex set of gravelly terraces and bowldery benches occurs along the sides of the Grand River channel. The principal gravelly terraces are from 15 to 45 feet above the channel floor, but some fragments are found at higher levels.

East of Matherton, on the south side of the channel, a well-defined bowldery terrace, evidently at one time part of the channel floor, now stands slightly above it for over 2 miles. About 2 miles above Lyons one of the finest terrace fragments in the valley runs along the north side of the channel for about 3 miles and is 30 to 35 feet above the swampy floor.

Between Matherton and Maple Rapids there are two islands in the old outlet channel, or rather one long, narrow island broken by a cut that does not reach to the bottom of the present channel. The island is a little over one-half mile in width at its east end, but in a mile narrows to less than one-fourth mile, and west of the transverse trough decreases still more, being at its extreme west end only 250 or 300 feet wide. The island is a remnant of the original till plain and is flat topped, with an altitude of 50 to 60 feet above the channel floor. Just west of Maple Rapids the channel divides in equal parts around this island, Maple River passing now on the north side. Hayworth Creek enters the south channel south of the east end of the island and runs northeast on the swampy floor to Maple River just below Maple Rapids. Islands like this are common at the head of most glacial outlets. In this particular place the early flow of the Imlay outlet river appears to have started the channel on the south side and a smaller stream that on the north, both at levels considerably above the present channel floor; subsequently the outlet river occupied and deepened both.

ALLUVIAL FANS.

After the Grand River channel was abandoned by the outlet river every stream that came into it began to build an alluvial fan. Above Lyons all the fans are small and the channel floor is very bowldery and swampy, scarcely any of it being fit for cultivation. At Lyons Grand River has built a large alluvial fan, which extends up as well as down the channel for some distance; it is this deposit that has crowded Maple River over against the north bank at Muir. Stony Creek has done the same 2 miles above Muir. The fan at Lyons also keeps Grand River to the north side of the valley for a mile or two west. From Lyons westward the lower parts of the channel floor have been silted up by the river, leaving only the tops of gravel

bars and a few bowldery patches projecting, thus turning much of the floor into arable land, which is, however, subject to overflow.

What has been said above concerning the Grand River channel refers only to its earlier and relatively small volume drainage and to the early work of the Imlay outlet river. This covers only the early part of the development of the great channel. For a relatively long time after these two stages the channel was occupied by the outlet river of the Huron-Erie glacial lakes, and it was then that the principal work was done in deepening and widening it to its present large dimensions. This part of its development and history is discussed in connection with glacial Lake Saginaw. (See pp. 360–361.)

GRADIENTS OF THE GLACIAL RIVERS.

After the retreat of the ice sheet the northern part of the region of the Great Lakes was affected by differential uplifts or warpings of the land. These movements are recorded in a wonderful way by the tilting of the old glacial-lake shore lines, which, although horizontal when they were made, are no longer so but rise gently toward the north or northeast. The uplifts and their effects on the old shore lines are discussed later (pp. 430, 461, 502–518). So far as known the southern part of the lake region was not affected by the uplifts, the old shore lines in that part still remaining horizontal. The dividing line between the affected and the unaffected areas is therefore not a nodal line, as it has sometimes been called, but a "hinge" line, the lands only on the north side having been affected.

The isobase of zero or the "hinge" line of the early deformation (see p. 342), which affected Lakes Maumee, Arkona, and Whittlesey, passes about west-northwest 4 or 5 miles north of Birmingham, Mich., from the middle of Lake St. Clair. The beaches of the Saginaw basin show that it extends in the same direction through that area. South of this line is the "area of horizontality," in which the beaches show substantially no deformation. All the drainage lines mentioned, excepting a little of the Imlay channel in eastern Genesee County, lie in this unaffected area. The gradients of the channels in this area therefore do not now differ from those which they had when they were made.

The head of the Holly channel in Hadley Township, Lapeer County, has an altitude of about 940 feet. About 2 miles west of Fowlerville, beyond which its identity is uncertain, it has an altitude of 880 feet. It therefore descends about 60 feet in a distance of about 45 miles.

The head of the Lookingglass channel was at the outlet of glacial Lake Davison, 3 miles north of Linden, where the altitude is about 850 feet. At its western end, where it entered the Grand River channel 2 miles northwest of Collins, its altitude is about 740 feet; the descent is 110 feet in about 70 miles. When the course of this river shifted to the route along the St. Johns moraine and down Stony Creek, the altitude at its mouth 2 miles east of Lyons was about the same as before, but the distance had been reduced to about 60 miles.

The highest Maumee beach in Goodland Township, Lapeer County, has an altitude of about 855 feet. The outlet river entered Genesee County at an altitude of about 800 feet, was at about 790 feet at the outlet of Kersley Lake near Duffield, entered the Grand River channel south of Maple Rapids at about 710 feet, and at Ionia was at approximately 700 feet. It probably included a glacial lake in Lapeer County in addition to the Kersley glacial lake in Genesee County. This gives a total descent of about 155 feet in 120 miles. But the head of the outlet was a little over 30 miles north of the hinge line in the direction of greatest uplift and the altitude there is about 55 feet higher than the highest Maumee beach in the area of horizontality (p. 342), so that about 55 feet must be subtracted from the present descent of the channel to find the actual descent at the time the river was flowing, and this would leave about 100 feet for the total descent in 120 miles.

At the time of the middle Maumee beach the altitude at the head of the channel was about 25 feet lower, or 830 feet above sea level, and the river then entered Lake Saginaw at Flushing, where the lake level was about 710 feet. But Flushing is about 12 miles north of the hinge line, and allowing 45 feet for uplift gives a descent of 75 feet in about 52 miles.

The Grand River channel was at first about 75 miles long, extending from the Arkona beach near Maple Rapids, with an altitude of about 710 feet (aneroid), to the upper beach of

Lake Chicago west of Grand Rapids, with an altitude of about 640 feet. It therefore descended about 70 feet in 75 miles. The floor on the divide north of Bannister is 72 feet above Saginaw Bay (652 feet above sea level), and when the channel extended back to the Warren beach in this vicinity its altitude was about 675 feet. The second beach of Lake Chicago has an altitude of about 620 feet, and the descent was therefore about 55 feet in a distance of about 100 miles. If Lake Chicago fell to its third beach while the outlet was flowing the descent would be about 75 feet in about 110 miles, for as the lake level fell in Lake Chicago the shore moved farther west from Grand Rapids.

It is thus seen that the rate of descent of these glacial rivers was generally less than 1 foot per mile, the highest rate being less than 1½ feet per mile and the least a little more than one-half foot per mile. It is worthy of note that the channel with the lowest gradient was occupied longest.

INTERLOBATE AREA ON THE "THUMB" OF MICHIGAN.

By Frank B. Taylor.

GENERAL FEATURES.

The moraines bend around the great interlobate angle on the "thumb" from northeast-southwest courses in western Lapeer and south-central Tuscola counties to northwest-southeast courses in western Sanilac County, and to north-south or east of south courses near the forty-third parallel in southeastern Lapeer and northwestern St. Clair counties. The first two or three of the moraines turn more sharply than the later members of the group. They run a little east of north in southwestern Lapeer County and a little east of south in the southeastern part. For these earlier members the bisecting line or axis of the apex of the interlobate angle runs a little west of north. With the later moraines the axis shifts to north and a little east of north.

The acuteness of this interlobate angle is relatively moderate. In other parts of the region the margins of two lobes at times faced each other directly and were partly in contact, sharply contesting for possession of the narrow strip of dumping ground between them; such conditions produce the most remarkable of the interlobate morainic deposits. On this part of the "thumb," however, the opposing margins were not in contact at the stage of recession under consideration. The first of the slender moraines curves gradually around an intervening open space nearly 20 miles wide at the south side of Lapeer County and 12 miles wide at the village of Lapeer, north of which it follows almost a semicircle. The angle grows less and less acute with the later moraines. A few of the moraines appear to be continuous around the reentrant, but others are represented by scattered fragments or are in a more or less tangled condition.

PRE-WISCONSIN RIDGES.

Outcrops of pre-Wisconsin till near East Dayton and the numerous reports in well records of hard till beneath the relatively soft Wisconsin drift at various points and especially in elevated places show that the older drift is present in large amount and that it forms the nucleus of some of the prominent ridges and knolls.

North of Mayville a group of large, irregular drift masses has a relief of 100 to 150 feet. The largest mass is in T. 11 N., R. 10 E. (Dayton Township), and runs a mile or two into the eastern part of T. 11 N., R. 11 E. (Fremont Township). As a whole it is roughly triangular in shape, measuring over 3 miles from north to south and about 7 miles from northeast to southwest. To the northeast, beyond a plain one-half to three-quarters of a mile wide, another smaller mass of the same character appears, lying mostly in sec. 31, Kingston Township, but partly also in Koylton, Wells, and Dayton townships. This has its eastern end a mile west of Kingston. South and east of Kingston other masses with very irregular forms rise rather abruptly out of a flat clay plain. The shapes and configurations of these drift masses and the absence in the particular localities of a converging ice movement to produce interlobate ridging suggest pre-Wisconsin age. Confirmation of this interpretation seems to be found in the presence of 75 to 100 feet of hardpan in deep wells located on these ridges and of outcrops of it on

some of the steep hillsides and in ravines. One outcrop appears on a hillside slope about three-quarters of a mile west of East Dayton, and another a mile farther north along the bed of Sucker Creek. The hardpan is a dark-colored stony till, much harder than the ordinary lighter-colored till of the surface, but in general appearance the same as outcrops of Illinoian till in regions farther south. Borings indicate that the older drift is not limited to these blocklike, somewhat isolated masses but underlies massively a large part of this region. There is reason to believe that it also forms the core or main undermass of a broad ridge which runs from the vicinity of Flushing northeastward to East Dayton and Kingston. The coating of Wisconsin drift on these large older masses appears to be relatively thin. The shapes they take and the depressions associated with them are probably in part due to pre-Wisconsin erosion.

DISTRIBUTION OF MORAINES.

PORTLAND (?) MORAINE.

The outer ridge of the morainic system in Lapeer County is the one already noted that runs near Hadley, in the southwestern part of the county, and is tentatively made the equivalent of the Portland moraine. It runs north-northeast from Hadley to the west branch of Flint River, passing about 4 miles west of Lapeer, and then curves to the east and southeast, passing about 7 miles east of the same city. West of Lapeer the morainic expression is rather gentle, there being a smooth, even ridge 1 to 1½ miles wide and 30 to 50 feet high. North of Lapeer the ridge is more irregular and reaches a width of 3 to 4 miles and embraces some conspicuous outwash aprons. This strength and width continue southeast to a point 2 or 3 miles west of Imlay. Farther south it is banked against the eastern base of the next earlier morainic system.

LYONS (?) MORAINE.

A second ridge runs near Elba in western Lapeer County and is thought to be the same as the Lyons moraine farther west. It is traceable with more or less distinctness and continuity around the curve in northern and eastern Lapeer County to Imlay. It is nowhere more than 2 or 3 miles distant from the moraine outside of it, and in the north and east parts of the county is generally less than 1 mile distant. In western Lapeer County it is hardly a mile wide, but in northern and eastern Lapeer County, as far south as Mill Creek, it is 2 to 3½ miles wide. From Mill Creek southward past Imlay it is again weak and finds its continuation in the Birmingham moraine of the Huron-Erie lobe. (See pp. 281–282.)

FOWLER MORAINE AND ASSOCIATED KNOLLS AND RIDGES.

The third ridge of the system in the reentrant angle is continuously traceable westward as the Fowler moraine. It comes from the southwest into western Lapeer County and extends north-northeast up to the south bluff of Flint River 2 miles west of Oregon station. Up to this point it is a strong, prominent ridge, 1 to 1½ miles wide, with a rather even crest. Beyond this point it has not been identified with certainty.

A distinct till ridge half a mile wide that begins just west of Columbiaville and runs southwest and west along the north side of Flint River may possibly be a part of the Fowler moraine, but the correlation seems doubtful, for the ridge appears to be clearly overridden a mile west of the county line by the Otter Lake (St. Johns ?) moraine. North of Columbiaville there is another east-west ridge less than half a mile wide and 3 miles long, and beyond that a larger east-west morainic tract over 4 miles long and 1½ miles wide. This last tract includes many kames and short esker ridges, and both this and the narrow ridge south of it are overridden by the same later moraine that overrides the fragment southwest of Columbiaville. If these fragments belong to the Fowler moraine then this moraine extends to the north side of Flint River north of Columbiaville, and its normal course would carry it in a wide curve around the north side of the interlobate area to the east side. But there is a wide gap without morainic deposits where this moraine might be looked for, and it does not seem possible at present to make definite cor-

relations across this space. The three fragments north of the river near Columbiaville seem plainly out of adjustment with the Otter Lake moraine, which overrides them all near the west line of Lapeer County, and they have no certain correlative eastward. Still they may be continued, after an interval of 10 or 12 miles, in the Imlay moraine, which seems to lack westward connections near North Branch, just as the Fowler moraine lacks eastward connections near Columbiaville.

IMLAY AND GOODLAND MORAINES.

The Imlay and Goodland moraines are closely contiguous. They begin about 3 miles southeast of North Branch and trend southeast along the east side of the Imlay channel to Mill Creek. Toward Mill Creek the two crests draw closer and are scarcely separable. South of Mill Creek both ridges are fainter but are more distinctly separated. The eastern one (the Goodland moraine) is faintly double in the southeastern part of T. 8 N., R. 12 E. (Goodland Township), and the western one (the Imlay moraine) has some gaps and short side ridges toward Imlay. The two ridges converge again toward Imlay, where they are about a mile apart. East from Imlay they are each one-fourth to one-half mile wide and are separated by a peat bog. These moraines are described below (p. 285).

A few miles north of Imlay, in the central part of Burnside Township, some large kames stand on the line of these moraines. They have two principal crests and their longer axes trend with the moraines northwest and southeast, the two main knobs being about a mile apart. (See pp. 271–272.)

OTTER LAKE (ST. JOHNS ?) MORAINE.

The Otter Lake moraine lies 1 to 1½ miles southeast of Otter Lake in northwestern Lapeer County. It comes up from the southwest out of Genesee County and is probably the continuation of the St. Johns moraine. South and southeast of Otter Lake it is strong, being nearly 2 miles wide and composed of four or five minor ridges. East of Otter Lake it is narrower and lower, about a mile wide, and is broken by a large esker which trends southeast.

The features north and northeast of Otter Lake are hard to interpret satisfactorily. Two alternatives are presented. According to one, at a break in the esker about 1½ miles northeast of Otter Lake the front of the next later moraine overrides the Otter Lake ridge. North of the esker a low, slender ridge, apparently the front member of the minor ridges just mentioned, comes up from the south and connects with two morainic spurs which project about a mile southeast. According to the other interpretation, a well-defined morainic belt, running northeast directly in line of prolongation of the Otter Lake moraine to a point 2 miles south of Mayville, forms the front of the complex morainic belt that extends eastward along the northern boundary of Lapeer County.

The available evidence seems to favor the first alternative; in that case the lower morainic deposits east of the esker and the morainic belt, running northeast from this point, all belong to the Otisville moraine rather than to the Otter Lake, and the Otter Lake moraine is overridden east of Otter Lake by the Otisville moraine. So far as known, the Otter Lake moraine has not been recognized at any point farther north or east.

OTISVILLE MORAINE.

As just described, the Otisville moraine passes just north of Otter Lake and thence apparently northeastward to a point 2 miles south of Mayville. In secs. 21 and 28, Watertown Township, its course is interrupted by a drainage channel bearing a stony deposit, partly morainic and partly resembling small kames. Stony morainic spurs that run out a mile or more to the southeast on both sides of the small stream which flows from Cedar Lake toward Fostoria seem distinctly older than the moraine and are partly overridden by it. To the northeast in Watertown Township the moraine is about a mile wide and is separated from the next moraine to the west by a fairly distinct, narrow bench—not a depression but a line of change of altitude and topography.

For 5 or 6 miles along this part of the moraine a sandy outwash fan overspreads the clay plain, covering nearly all of Watertown Township that lies southeast of the moraine and running south into Marathon Township for a mile or more.

From a reentrant angle in the moraine south of Mayville gravelly outwash spreads southeast for a mile or two, east of which a narrower and weaker morainic ridge runs eastward with front convex to the south. Two miles northwest of Silverwood this ridge sinks beneath sandy outwash from the next later moraine but is apparently continued about 2 miles east of Silverwood by a moraine of about the same strength and character, trending southeast, which emerges from the east side of the outwash deposit.

After emerging from the outwash apron this moraine passes just south of Clifford and continues southeasterly into T. 9 N., R. 12 E. (Burnside Township). It is very much broken and toward Burnside becomes an irregular belt of scattered knolls. In secs. 5 and 6, Burnside Township, the channel of a glacial river from the northeast breaks through the moraine in a westward course to the Imlay channel south of North Branch. Southward from this drainage line as far as the southeast corner of Burnside Township the scattered deposits continue, but south of this along the county line the country is a wide, flat swamp with only a few knolls rising 2 to 4 feet above it. A line of faint knolls answering this description passes from the southeast corner of T. 8 N., R. 12 E. (Goodland Township), southeasterly into T. 7 N., R. 13 E. (Mussey Township), St. Clair County, where it meets a large transverse ridge extending toward the southwest. In Burnside Township the eastern knoll of "Deanville Mountain" stands about in line with this moraine but probably belongs to the next earlier moraine. The relations in this vicinity, however, are not certain.

DEANVILLE MORAINE.

West of Index a slender, even-crested moraine, here called the Deanville moraine, runs directly south past Deanville and in broken form to Mill Creek at the county line. Beyond, in the western part of the township of Lynn, lies a great swamp, in which nothing representing this moraine was observed. Beyond the swamp, however, in the line of trend of the moraine produced from where last seen south of Deanville, a faint ridge continues to the southeast in northeast Mussey Township. Another fainter, more broken ridge runs parallel with this about a mile to the east. These faint ridges begin near the south side of one of the transverse ridges which cross this region from the northeast. On the north side of this transverse ridge two morainic knolls stand in about the trend of the Deanville moraine, but their longer axes are parallel with the transverse ridge. The relations of this moraine are not clear. It appears to be older than the Mayville moraine, but its connections toward the north and west are not known.

MAYVILLE MORAINE.

The Mayville moraine appears to be a continuation of the Flint moraine. It enters Watertown Township, Tuscola County, in secs. 30 and 19 and extends thence directly northeast to Mayville. In most of this interval it is high and rugged and nearly 2 miles wide. At Mayville it turns more easterly, bending south a little, like the Otisville moraine, which is a mile or so south of it. Gradually it turns southeast, passing 1½ miles northeast of Clifford, runs east nearly to Marlette, turns again southeast, bending east at the county line 3 miles southeast of Marlette, and thence runs east to the northeast corner of Lapeer County. At this point it is broken by a swampy trough which runs north along Cass River and southwest to the Imlay channel south of North Branch. Whether it finds its continuation southward in the Deanville moraine or eastward in a chain of morainic knolls connecting with the Owosso moraine northwest of Omard remains undecided, though the Deanville line seems the more probable.

OWOSSO MORAINE.

A moraine regarded as the probable northeastward extension of the Owosso moraine passes 1½ miles southeast of Millington (p. 243) and runs northeastward to Murphys Lake as a low,

smooth ridge one-half to three-fourths of a mile wide. Northeastward from Murphys Lake it runs along the inner base of the Mayville moraine, not in the form of a ridge but banked up against the earlier ridge as a belt of morainic ground with a definite drainage line along its upper edge. North of Mayville it connects with a group of large irregular drift masses that resemble interlobate deposits, but which, as already noted (p. 261), seem to be largely pre-Wisconsin drift.

Half a mile to a mile south of East Dayton knolls of sand and fine gravel 20 to 25 feet high cover a considerable part of the surface but end abruptly at the north base of the higher ground in secs. 9 and 10. The higher ground is all stony till with no outwash covering. Just west of the corner at East Dayton a small drainage trough runs southwest.

The sand knolls and the little drainage trough seem to be products of border drainage at or near the front of the ice when the front rested on or against the north slope at East Dayton. Many kames and sandy deposits southeast of Cat Lake, in secs. 17 and 18, are probably associated with streams issuing from the ice in that depression.

YALE MORAINE.

On the east side of the interlobate tract the Owosso moraine apparently finds continuation from the vicinity of Kingston in an ill-defined, very much broken line of low morainic knolls which run southeast through northeastern Koylton, central Marlette, and central Flynn townships to the vicinity of Omard. The broken, faint character of the morainic forms in this interval leaves their identity and correlation somewhat uncertain. However, a better-defined moraine, known as the Yale, appears 3 or 4 miles northwest of Omard and, passing a mile west of this place, continues in better form southeast into Speaker Township. It passes a mile southwest of Speaker as a strong ridge with its front slightly concave to the southwest. Just opposite Speaker it crosses at right angles one of the large transverse ridges of this region. To the south for a mile or two its expression is faint, but near Yale it begins again as a well-developed ridge and runs south along the east side of Mill Creek into Kenockee Township, where it becomes water-laid.

JUNIATA MORAINE AND BOWLDER BELT.

From Millington a faint suggestion of a moraine extends northeastward toward Juniata. West and northwest of Murphys Lake it is manifested by low morainic knolls and south and east of Juniata its place is marked by low bowldery knolls and ridges. In secs. 15, 16, and 17, Fremont Township, there is another morainic mass with kames; and in secs. 1, 2, and 3 of the same township and north along the east side of secs. 36 and 25, Indian Fields Township, there is a high, narrow, rugged ridge which is mainly morainic but which contains also two or three kames of large size. Some of the gravels here are overlain by till, having been apparently overridden by a readvance of the ice.

A well-defined bowlder belt associated with this moraine becomes prominent about a mile northeast of Juniata, and runs thence northeast past the large kames just described and across Wells Township into Novesta Township, where it turns eastward past Deford and Novesta and extends a little way southeastward into Evergreen Township, Sanilac County.

There seems to be no doubt that much of this bowldery belt marks the position of the ice front during the building of the Juniata moraine, although it is also associated with a great drainage line which followed the front of the ice for a brief time and entered Lake Saginaw, probably south of Juniata.

For 12 miles northeastward from the southwest corner of Wells Township no definite morainic ridge was observed. In the central part of Novesta Township, however, a strong morainic ridge runs northeast, crossing into Sanilac County from sec. 36, Elkland Township. Possibly this is the northeastward continuation of the Juniata moraine, but, although it lies in the trend of this moraine, such a correlation seems uncertain, not only on account of the wide interval, but because the deposit as a whole seems to be more of the nature of an interlobate moraine.

INTERLOBATE DEPOSITS AND SCATTERED RIDGES IN SANILAC COUNTY.

In Evergreen, Greenleaf, and Austin townships, large irregular masses of stony till which seem to show no particular trend or arrangement, except on the east and northwest sides, are cut up into irregular patches by a number of branching and interlacing glacial channels and spillways. On the east and northwest sides they lie closely parallel with the front of the Port Huron morainic system and are separated from it only by the channel of the outlet of Lake Whittlesey.

Along the east side a range of hills runs north-northwest about 7 miles from the middle of Minden Township across the southwest corner of Paris Township to the center of Bingham Township, Huron County. Although parallel with the front of the Port Huron system, this range of hills shows forms that bear some resemblance to drumlins; in fact, it is made up of smooth, oval hills with their axes coincident with the trend of the group. Other isolated hills of this type stand in eastern Austin Township. The larger hills reach a height of 50 to 60 feet. These hills are not perfect drumlins, but a few of them fall little short of typical forms. The occurrence of drumlins or drumloid hills in this angle in front of the Port Huron system finds a complement on the Canadian side of this same ice lobe which makes for symmetry in a very striking way, viz, near Clinton, Ontario, a considerable number of small but well-formed drumlins stand in front of a reentrant angle in this same moraine. The angle, however, is not acute like that on the "thumb."

In Sanilac County west of Black River, east of the moraine last described and south of the interlobate area in the northwestern part, scarcely any morainic features appear. Almost the entire area is a flat clay plain, and only a few small fragments, none of them more than a mile or two in length and few more than 20 feet high, can be classed as morainic. Eskers, kames, and transverse ridges are more prominent than morainic features. The fragments appear to be scattered without arrangement or order, except near Shabbona, whence a series of low clay knolls runs south and southeast into Moore Township, and after an interval of 2 or 3 miles is perhaps extended in more knolls of the same character running south 3 or 4 miles from Elmer; these knolls, however, are so small and scattered that it is doubtful whether they mark a halting place of the ice front. From Lamotte eastward and southward along Cass River is another broken line with low knolls, which may be morainic, but which, from their composition, seem more like a broken esker or a line of kames. (See p. 270.)

TRANSVERSE RIDGES.

In southern Sanilac and northwestern St. Clair counties and in less degree in northeastern Lapeer County several ridges lie directly across the trend of the moraines and in places are crossed by moraines in such a way as to show that they are the earlier. They are composed largely of clay with large numbers of bowlders, and some of them have associated gravel and sand deposits. Two or three seem to be composed mainly of bowldery clay, but have a veneering of assorted material partly in the form of kames and partly a flat surface covering.

One of the largest transverse ridges, 40 or 50 feet high and more than a mile wide, runs south-southwest from the middle of Washington Township, Sanilac County. After a swampy interval of 4 miles it reappears, in southeast Elk Township, as an irregular line of ridges connecting southward with an extensive kame area near Melvin in central Speaker Township. Here it turns west-southwest and is crossed by the Yale moraine, which appears to be distinctly younger. From the crossing it runs in a remarkably straight course to Mill Creek in sec. 7, Lynn Township, St. Clair County. In this last interval it carries large numbers of bowlders and contains also much gravel.

Another transverse ridge, parallel with the one just described, begins in the northeast part of Buel Township, where two ridges of smaller size lie close together. Beyond a gap of about a mile it reappears as a prominent ridge running southwest, passes west of Buel, and crosses northwest Fremont Township into eastern Speaker Township, where it too is crossed by the Yale moraine.

At the bend of Mill Creek 2 miles northwest of Yale two ridges seem to start from the same point. One, which is notable for its bowlders, runs west to the termination of the ridge just mentioned, in sec. 7, Lynn Township. The other and stronger runs south for 6 miles and then turns southwest on a nearly straight line toward Almont, dying out toward the southwest in sec. 31, Mussey Township. Just north of the southwest section of the ridge lie shorter fragments parallel with it and one longer fragment which seems to converge southwestward with it.

Other features, apparently of the same kind but smaller, lie in Lapeer County. One runs southwest from Brown City toward the Deanville kames and is probably related to them. Another runs southwest through Burlington Township to the Imlay channel, a mile north of North Branch.

The origin of the transverse ridges can not be fully explained at present. It seems clear, however, that they are related in some way to strong lines of drainage in or under the ice, and are therefore in a certain sense analogous to eskers, although not of typical esker form. The one that runs southwest from Melvin and the one which converges with it from the east seem to have found their southwestward prolongation up the valley of Mill Creek through Goodland Township and in a general way toward the interlobate angle, when that angle was acute and was situated on the high ground of southern Lapeer County. The other large ridge points in a general way toward the same place. It is conceived that these ridges were produced not by subglacial streams but by streams whose positions were inherited from lines of drainage which led to the interlobate angle when the ice front was in southern Lapeer County, and that the ridges themselves were developed at a later time when the ice front had receded to the Imlay or the next later moraine and had become relatively thin at the margin, so that the streams encountered dirty basal layers of the ice.

TOPOGRAPHY.

ALTITUDE AND RELIEF.

The moraines of this district do not show much variation in altitude, excepting in the southern part of Tuscola County between Otter Lake and Kingston. When the ice front rested on the high moraines at the south edge of Lapeer County the interlobate angle was acute and the front lines of the two lobes faced each other almost directly. At the time of the building of the outer two moraines the ice front had dropped from its high position to the plain of central Lapeer County and the acute angle had opened out and become nearly a right angle. At the time of the building of the later moraines which bend around the north side of Lapeer County the angle had changed to a curve, at first a semicircle but later more open, with a sweep of 20 to 25 miles. Though the area considered here is in a broad sense interlobate, at the particular stages discussed true interlobate conditions of deposition did not exist, for there was no conflict of opposing or converging ice. The front curved gradually from one lobe to the other around a wide unoccupied area throughout which normal conditions of marginal deposition prevailed. At only one or two places did small local reentrants in the ice front cause a heaping of deposits from two sides. This relation—a broad curve instead of a sharp angle—naturally led to the making of moraines with more even crest altitudes than would otherwise have been built.

In western Lapeer County the crests of the outer two moraines have altitudes 880 and 890 feet above sea level, only a few small areas reaching 900 feet; their relief is seldom more than 50 or 60 feet, with an average of 35 to 40 feet. In central Lapeer County these two moraines are developed in much greater strength, some knolls rising to 960 feet, though the general altitude is about 900 feet. From Flint River in Rich and Deerfield townships southeastward to Imlay the altitude is mostly 900 to 950 feet. In many places the relief is 80 to 100 feet and in two or three over 150 feet. The Otter Lake moraine rises to about 925 feet south of Otter Lake and has a relief of 50 to 60 feet.

The Mayville moraine between Otter Lake and Mayville forms the most extensive high ground in the district, much of it rising above 900 feet and one hilltop a mile west of Mayville

above 1,000 feet. Two areas in central and southeastern Dayton Township rise above 940 feet and one small area in southern Koylton Township above 900 feet. The Owosso moraine rises from about 780 feet south of Murphys Lake to about 850 feet near East Dayton; its relief varies from 20 or 30 feet at the south to 50 or 60 feet at the north. Except on the high kames in central and northeastern Fremont Township, the Juniata moraine has an altitude of 770 to 780 feet.

The relief between Otter Lake and Mayville is the greatest in the district with the exception of the Deanville kames mentioned below. (See p. 271.) Relief of 80 to 100 feet is common and the rise from Murphys Lake to the east 1½ miles is 200 feet or more. In the high areas of Dayton Township the relief is 100 to 150 feet. Except for two or three points that rise to 50 or 60 feet in Fremont and Indian Fields townships, the Juniata moraine has scarcely any perceptible relief and in the bowldery belt in Wells and Novesta townships lacks what little it has elsewhere.

In northeastern Lapeer and southwestern Sanilac counties the moraine crests rise above 900 feet in a few places but are mostly between 850 and 900 feet. The Deanville kames rise at their summits to about 1,030 and 1,060 feet, respectively (aneroid). The two highest knobs are 1 mile and 1½ miles from the Imlay channel, which has there an altitude of 790 feet, and they therefore rise above it about 240 and 270 feet, respectively. These are the highest points on the "thumb" north of the high area at the south line of Lapeer County.

The interlobate deposits in northwestern Sanilac County for the most part rise but little above 820 feet, though a few points reach as much as 850 or 860 feet. The relief generally is not more than 40 feet. The scattered ridges in Sanilac County have altitudes mostly between 775 and 800 feet, and their relief ranges between 10 and 30 feet. The transverse ridges have crest altitudes of 800 to 850 feet with relief ranging between 10 and 50 feet.

CHARACTER.

Up to the middle of Oregon Township the outer two moraines are relatively even, smooth ridges, with mild swell and sag topography, but as they turn northeast into Mayfield and Deerfield townships they become much more irregular and varied. One of the finest types of swell and sag topography seen in this part of Michigan is on the road running 2 miles southeast from Columbiaville. In northern Mayfield, southern Deerfield, central and western Arcadia, and northern Attica townships, especially in the last three, the outer moraine shows knob and basin topography. In northwestern Attica the development is more pronounced, especially north of Attica station. The deposition of the drift in the belt between Attica and central Deerfield was considerably influenced by waters issuing from the ice. Probably three-quarters of the area between these points is of a somewhat irregular swell and sag type, but much of it consists of small plateaus with undulating surfaces, like those in northern Attica and southern Arcadia. The second or Lyons moraine from the bend of Flint River, in the southeastern part of Rich Township, is similar to the outer moraine in its topographic expression but has some higher kames close to the Imlay channel, and for 6 or 7 miles north of Imlay it has a more pronounced development of knob and basin topography. Some of the basins 3 or 4 miles to the north are large and deep.

The narrow ridge running southwest from Columbiaville on the north side of Flint River is of smooth swell and sag type.

The Otter Lake moraine is composed of several parallel ridges close together with rather strong swell and sag expression and some basins. The morainic ground in north-central Marathon Township is associated with large esker ridges and has irregular topography. It has knobs and basins, two or three of the basins being rather large. South of this area a small till plain is inclosed like a basin by a sharp narrow bowldery ridge 15 to 25 feet high which extends around its south and east sides.

The Otisville moraine is very rugged north of Otter Lake and has many knobs and basins associated with the esker formation. The rest of this moraine to the neighborhood of Silverwood has a moderate swell and sag topography. Southeastward into Burnside Township, if its identification there is correct, it has mainly a swell and sag topography, but with some pronounced basins.

The Mayville moraine has a great development of knob and basin topography in western Watertown Township in association with the esker trough leading south from Murphys Lake. The rest of this moraine to the east line of Dayton Township has a strong swell and sag topography but includes many basins, some of them on its highest parts.

The Owosso moraine has a rather mild swell and sag topography as far as a point north of Mayville, except along its outer border, where it has knobs and basins in association with the gravels of the Butternut border drainage line. Farther northeast, on the high ground of Fremont and Dayton townships, it has a varied expression, mainly swell and sag, but with knobs and basins along its front, especially southeast of Cat Lake.

In areas where it has little relief, the Juniata moraine is mainly swell and sag, but in each of the three areas where it has strong relief it has more or less knob and basin topography, especially in the largest high area in northern Fremont Township.

Near Marlette the Mayville moraine shows mostly swell and sag topography on the ridges, but in some places it has many basins and on its inner border many swampy hollows.

The Deanville moraine is a smooth ridge along its front but is bordered by scattered irregular knolls for a mile or two on its eastern side.

The ill-defined morainic belt running east through southern Koylton has mainly a swell and sag topography, but has also a considerable number of basins and many swampy recesses on its inner side. This expression continues nearly to Omard, but beyond that the form of the Yale moraine is mainly swell and sag to the kame area in the central part of Speaker Township, where knob and basin topography and kames are developed in connection with the overriding of the large transverse ridge.

The ill-defined morainic belt running southeast from Kingston and the high area just west has some knobs and many basins.

The interlobate region in northwestern Sanilac County has a broad swell and sag topography with a moderate development of drumlin-like forms in the eastern part.

Almost all the scattered ridges in western Sanilac County are low swells. Some, however, are sharp and narrow, but these more or less resemble eskers.

The transverse stony ridges are mainly smooth, with only mild swell and sag forms, but where their tops bear kames they are rougher and have many basins. Where they are crossed by the moraines they have also a mixed topography.

STRUCTURE OF THE DRIFT.

COMPOSITION.

The moraines of the district are composed mainly of stony clay, the proportion of bowlders and pebbles being considerably greater than in the moraines west of Lapeer County. The more pronounced interlobate deposits in central Lapeer County, especially those south of the Imlay channel between Oregon and Imlay townships, contain a very large share of coarse materials. The moraines in this interval approach more nearly the interlobate type, in which more or less concentration of coarse sediments is characteristic. The moraines in Marathon and Watertown townships also contain much coarse material, but the group of moraines that sweep through southern Tuscola County around into Sanilac, eastern Lapeer, and northwestern St. Clair counties are more largely composed of clay. Except in their higher parts, the Owosso and Juniata moraines are composed largely of clay with very little coarse material.

The transverse ridges are composed mainly of very stony till, bowlders being generally very plentiful upon them. Considerable quantities of gravel and sand are associated with these ridges in places, especially upon the tops of the larger ones in Washington and Elk townships.

No very extensive sand or gravel deposits were found. The outwash apron in Watertown and Marathon townships is the largest. Two or three smaller ones occur in central Lapeer County.

Between the Arkona beaches and Cass River a large share of the surface is covered with fine sand. The Arkona beach ridges are composed of gravel, but the Warren beach is generally sandy.

Borings have not disclosed any thick or extensive beds of gravel or sand beneath the surface sheet of till. Almost invariably they find the whole depth to rock to be occupied by till and hardpan or old till (see p. 261), with only a few thin layers of sand or gravel. The drift in this district strongly contrasts in this respect with that of the high region in the northern part of the southern peninsula, where in many places a relatively thin coating of till covers great depths of gravel or sand.

THICKNESS.

In Lapeer County the thickness of drift ranges from 50 to 200 feet, with an average of a little more than 100 feet. In the morainic belt in southern Tuscola County the thickness is greater, but on the flat plain to the north and on the plains in Sanilac County it ranges from 20 to 120 feet. At Brown City near the Lapeer County line two wells pass through 190 and 213 feet of drift. In northwestern St. Clair County the thickness varies from 150 to 225 feet. Some of the deeper borings probably show the location of buried valleys in the rock surface.

TILL PLAINS.

Till plains are for the most part very broken and patchy. This arises from the confusion and overlapping of the moraines in the interlobate area. The plain in Rich Township, Lapeer County, is perhaps of till, but is covered to some extent with lake clays. A few small till plains occurring in the midst of morainic deposits are quite remarkable, because of their striking contrast to the moraines; such are the one west of Columbiaville, a smaller one to the north, and a small one between Mayville and Silverwood.

The most important till plain of this district, however, is that which occupies a large part of west-central Sanilac County and runs over into Tuscola County in Novesta, Kingston, Ellington, and Wells townships. It lies northeast of the morainic belt, west of Black River and Elk Creek and south of the interlobate district in northwestern Sanilac County, covering 450 to 500 square miles. It contains only a few small fragmentary morainic ridges and a few eskers. Its altitude is mostly between 800 and 850 feet. The drift is relatively thin, varying generally between 20 and 50 feet, is less stony than that of the moraines, and is not covered with lake clay.

Other smaller plain areas of till lie in southern Sanilac and northern St. Clair counties, but are considerably broken by the moraines and transverse ridges.

ESKERS.

LAMOTTE ESKER.

A rather remarkable esker 11 miles long stands on the till plain of western Sanilac County. For about 6 miles it runs south in the western tier of sections of Elmer Township along the medial line of a swamp that follows the south branch of Cass River. In this part the esker, which is about 30 feet high, is broken into several pieces, but they are ridge forms and are aligned after the manner of true eskers. In some respects, however, the ridge is not a normal esker, for the fragments contain a considerable amount of till and in places many bowlders. The fact, however, that they are composed also largely of gravel and sand, taken in connection with their form, alignment, and relation to the swamp, seem to show that they are in reality a modified esker.

In sec. 6, Elmer Township, the ridge (tracing it headward) turns sharply northwest and at about 2 miles divides in two branches, one continuing northwest for about a mile and the other running directly west for over 2 miles and turning northwest at its end. This east-west section is a more typical esker. It is more generally composed of gravel and sand and one or two of its knobs rise 60 feet above the surrounding plain.

Another ridge about 3 miles long crosses the county line a mile south of Novesta and extends southeast toward the Lamotte esker. Its gravelly knobs seem more like kames

than parts of an esker, but it is in all probability a part of the same formation as the Lamotte esker.

KOYLTON ESKERS.

In the eastern part of Koylton Township two finely formed eskers run southwest and end in a swampy trough which runs south to Clifford. The eastern esker is on the line between secs. 14 and 23, Koylton Township; after following a winding course for over one-half mile west, it turns southwest for 1½ miles and becomes considerably higher and more bulky. It is an excellent type of esker, 40 to 50 feet high and with very steep sides and narrow undulating top composed of coarse gravel and pebbles.

The western esker, which is not so well developed, runs about 1½ miles to the same swampy trough. A chain of gravelly knolls running south and curving southwest for about 1½ miles from Kingston seems like a broken and poorly developed esker.

OTTER LAKE ESKER.

The great gulf in the morainic deposits in the western part of Watertown Township, Tuscola County, contains many kames and some short esker-like ridges. At its southern end, where it emerges on the higher ground, an esker of large size and typical form runs south from the middle of sec. 29 about to the middle of sec. 32. The ridge is 100 to 200 feet wide on top and 70 or 80 feet high, and the troughs on the two sides are ponds of considerable depth. South of this fragment the symmetrical form of the esker is broken for nearly a mile to the middle of sec. 5, Marathon Township, Lapeer County, the break appearing to mark the front of the Otisville moraine at the time the ridge to the north was made. At the break there is some offsetting, for when the esker begins again it runs to the southeast. For about a mile it is not so strong and high and is broken abruptly by a pond in the middle of sec. 9. At the east side of the pond the esker rises sharply to a height of 70 or 80 feet and continues southeastward into a jumble of kames and ridges and morainic knolls which fills a considerable area in secs. 10, 11, 14, and 15. At the east end of this area another short gravelly ridge runs southeast in secs. 14 and 13 to the bank of the Imlay channel, half a mile distant.

OREGON ESKER.

In sec. 13, Richfield Township, Genesee County, a finely developed esker, 50 or 60 feet high with deep troughs along its sides, runs south and, turning southeast across the county line, crosses sec. 19 into sec. 29, Oregon Township, Lapeer County. This esker is remarkable for the way in which it terminates. It passes through the Fowler moraine to the trough in front and there merges abruptly into a small gravelly delta fan, which measures about three-quarters of a mile by half a mile and is typically developed in its relation to the esker.

MISCELLANEOUS SMALL ESKERS.

About 3 miles northwest of Imlay a large gravel ridge nearly a mile long in the trough of Mill Creek resembles much in form and situation an esker, although it is in some respects like a kame. It is higher and wider at its western end where it emerges into the Lum channel. A number of smaller eskers are situated in various parts of this district. Several short, finely formed eskers are associated with the Mayfield kames.

KAMES.

DEANVILLE KAMES.

A mile and a half west of Deanville, in Burnside Township, Lapeer County, stands Deanville Mountain, a cluster of high kames composed principally of gravel. Many bowlders, mostly small ones, appear in the gravel, and stony till is seen in it in some places, especially toward the base. Like most other kames, these are irregular in outline and have many knobs and basins at different levels.

The Deanville kames are roughly divided into three large masses. The largest mass stands on the east side in secs. 27 and 22; a somewhat smaller one joins it closely on the southwest in southwestern sec. 27; the third lies a mile west of the first, mostly in sec. 28, but partly in sec. 21, Burnside Township. By aneroid measurement from Brown City the eastern knob has an altitude of about 1,060 feet above sea level, the western one 1,030 feet, and the southern one a little less. The divide on the floor of the Imlay channel 1½ miles southwest of the kames has an altitude of about 790 feet, so that the highest knobs rise about 270 and 240 feet, respectively, above that level. They rise nearly 200 feet above the general level of the surrounding country.

Along the east side of the eastern knob there is a well-marked depression or foss into which the descent is steep. This depression was evidently occupied by the ice and the steep slope marks the contact of the ice mass.

The longer axes of all three hills are northwest and southeast, or in accord with the trend of the moraines, to which they seem to belong. As already noted (p. 263), two well-defined moraines run southeast from about 3 miles southeast of North Branch. Their crests are only a mile apart, but they run as two distinct individuals southeastward to the vicinity of the kames. If the kames were inset a little from the front of the ice, as seems probable, their relations and the interval between them seem to accord well with the two moraines referred to.

At one time the railroad ran a spur from Brown City to the north end of the eastern kame and a large amount of gravel was taken out for ballast. The pit at the time of the writer's visit, however, was old and showed few details of structure, except that it had a great depth of coarse gravel and large numbers of bowlders.

MAYFIELD KAMES.

The Mayfield kames stand in the northwest corner of Mayfield Township, Lapeer County. The highest knob, which reaches an altitude of 950 feet, is in sec. 7, and is adjoined by several smaller kames, especially on the southeast. North and northeast of the high knob a jumbled country of about a square mile is covered with knobs and basins and very pronounced short esker ridges trending northwest and southeast. The highest knob is covered at its top with coarse gravel and pebbles and is steep sided and narrow topped. The lower ground among the esker ridges is unusually rough.

This deposit lies in the trend of the Otter Lake esker and it seems quite likely that it was deposited by the same glacial stream at an earlier stage of retreat.

GOODLAND KAME.

Southwest of the Deanville kames, on the west bank of the Imlay channel, stands the Goodland kame, a double-topped kame of large proportions but of somewhat lower height. From the trend of the moraines this kame appears to have been produced by the same glacial stream that made the Deanville kames, but at an earlier stage of retreat.

About 2½ miles northwest of this kame, and standing also on the west bank of the Imlay channel, there is another large kame which reaches about 1,020 feet altitude (aneroid).

JUNIATA KAME.

In the highest part of the Juniata moraine on the north line of sec. 2, Fremont Township, Tuscola County, a large kame known as the Juniata rises considerably above the surrounding country, but its altitude was not measured. It is somewhat elongated toward the southeast. East of this 1½ miles a broader knob rises still higher and appears to be partly of the nature of a kame but partly morainic. A pit on the flank of this hill showed bowldery till distinctly overlying clean cross-bedded gravels and suggested an overridden kame.

MISCELLANEOUS KAMES.

Some parts of the transverse ridges in Buel and Elk townships, Sanilac County, appear to be largely of the nature of kames, this being especially true of the ridge north and west of Buel, which seems to be composed mainly of kames; it rises 40 to 50 feet above the plain. In northeastern Buel two ridges are evidently kames in part, but they stand at a lower level and were largely modified by wave action at the time of Lake Whittlesey.

A narrow ridge east and northeast of Peck in Elk Township is largely composed of kames. A smaller but quite prominent kame cluster occurs 3 miles north of Peck, and a number of kames stand east and northeast of Melvin, in Speaker Township. Most of these kames rest on morainic ground or stony till. In the transverse ridges the kames seem generally to overlie ridges of stony till, the main undermass being of this composition.

GLACIAL DRAINAGE.

OUTWASH APRONS AND DELTA DEPOSITS.

MAYFIELD OUTWASH DELTA.

The quantity of gravelly and sandy outwash which issued directly from the ice front in this district is surprisingly small, only three or four deposits being of sufficient importance to require mention.

In the northern part of Mayfield Township, 5 or 6 miles north of Lapeer, a small but rather remarkable outwash deposit covers the whole of sec. 10 and small parts of all the adjacent sections. It is surrounded on its east, west, and north sides by a rugged, bowldery morainic deposit, which descends steeply to the lower ground on its inner side. This narrow morainic deposit seems like a retaining wall around the sides of the outwash and appears to represent an ice-contact surface. Except perhaps at a few points on its east side it does not rise above the level of the gravelly deposit.

The exceptional thing about this deposit is the height to which it rises above the surrounding country. Its surface has an altitude of about 960 feet, whereas the till plain immediately south of it and extending to Lapeer has an altitude of 825 to 850 feet. Its top is almost flat, but slopes a little to the southwest, and its sand is notably finer at the south than at the morainic rim.

The formation seems much like a delta formed in a lake and the situation favors that origin. The flat ground north and east of Lapeer seems much like a lake floor and has in fact a deposit of pebbleless lake clay in some of its lower parts. There was, however, a lake on this plain at a later time and the clays may belong to that.

If this deposit was made in a lake it must have been at a slightly earlier stage of the glacial retreat than that represented by the moraine that runs past Hadley and the glacial river that flowed along its border, for the general crest level of the moraine is under 900 feet west of Lapeer and the head of the glacial river near Hadley is not above 840 or 850 feet. Some scattered morainic knolls in and west of Lapeer running south and others 3 or 4 miles east of Lapeer may, perhaps, represent the position of the ice at that time.

This high outwash deposit is one of few deposits which the writer has seen in the West that bear a close resemblance to the "sand plains" described by New England geologists. The outwash apron that bears the university campus and much of the city of Ann Arbor, Mich., is another of this type; it is described by Mr. Leverett in the Ann Arbor folio.

FOSTORIA OUTWASH APRON.

The largest outwash deposit in the district is that which lies around Fostoria in Watertown Township, Tuscola County. It is 9 or 10 square miles in area and lies in contact with the front of the Otisville moraine for about 6 miles. It may have issued from the ice front all along the line of contact, but a considerable part of it appears to have come from a gap in

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the moraine northwest of Fostoria, where there are kames and much very stony ground with knobs and basins.

The surface of this deposit is quite uneven, especially in its western part, which contains a number of basins. Its eastern part is composed mainly of fine gravel and sand and its altitude along the front of the moraine is 850 to 860 feet. It appears to have been deposited in the border of a shallow lake.

SILVERWOOD OUTWASH APRON.

From the front of the Mayville moraine a plain of sandy and gravelly outwash stretches 1½ miles south, reaching nearly to Silverwood and extending a mile or two farther south on each side of that place. Its composition grows finer toward its outer edge. For 3 or 4 miles the Otisville moraine appears to be completely buried under this deposit, the upper edge of which has an altitude of about 860 feet.

This outwash apron has some peculiar features. South and southeast of Silverwood its front has a sort of digitate form, several narrow, finger-like ridges of sandy gravel, some of them a third to a half mile long, project south-southwest in straight lines over the flat, smooth clay plain. These ridges are 10 or 15 feet high and have some resemblance to the lobations seen on the fronts of some deltas but are too narrow and too precisely parallel for such an origin to be probable. It has also been suggested that they may have been formed in channels in a dead ice mass which covered the plain. As yet no explanation offered seems altogether satisfactory. The deposit as a whole, however, appears to have been laid down in a shallow lake.

DRAINAGE SOUTH OF IMLAY CHANNEL.

HOLLY CHANNEL AND LAPEER GLACIAL LAKE.

The headward part of the Holly channel is in Lapeer County near Hadley, and it seems quite certain that central Lapeer County was occupied by a relatively small glacial lake which lay chiefly in Lapeer, Mayfield, and Attica townships and partly in Oregon and Elba townships, and which discharged southwestward through the Holly glacial river. This lake, known as the Lapeer glacial lake, received drainage directly from the ice around the interlobate angle and drainage from the ice border for some distance south on the east side of the high land, the latter probably entering through the channel running north and northwest from Dryden.

ELBA CHANNEL.

The Elba channel is nearly as large as the Holly and was apparently but little lower. The Lapeer glacial lake was shallow when it discharged through the Holly channel, so it is doubtful whether it remained in existence with the lower outlet. There are two or three passages through the Hadley ridge (Portland moraine) which might have allowed the waters to go westward to the Elba channel. One of these is southwest by way of Bronson Lake in Oregon Township, and another through Nipissing Lake in Elba Township. The even spread of the gravel fan at the end of the Oregon esker seems to suggest still but shallow water for its deposition, or at any rate water with too little current to effect the formation of the fan. The drainage of this area went first past Atlas to the Lookingglass channel and afterward to the Davison glacial lake.

LUM CHANNEL.

The Lum channel is remarkable. It is only a fragment, extending northwest from about 2 miles north of Imlay to Flint River in northern Deerfield Township, parallel to the part of the Imlay channel between Mill Creek and Rich Township. This channel is a mile and in some parts more than a mile wide—two or three times as wide as the narrow part of the Imlay channel. Its banks, especially in its southern and middle parts, stand 70 to 90 feet above its floor; toward the northwest they are lower. From Mill Creek to Kings Mills the eastern bank is a high, rugged moraine, so steep along its front facing the channel that it seems certain that it was undercut by a river.

The significance of this channel in the lake history is largely problematic, for it is only an isolated fragment cut off from direct connection with the only glacial lake that can be supposed to have been connected with it. The river that made it must have been fully as large as the Imlay outlet river, for its proportions resemble those of the larger sections of the latter—those, for instance, between Richfield and Flint in Genesee County. It is one of those suggestive fragments which shows the complexity of the lake history without shedding a clear light on the events connected with its origin.

North and west of Imlay a rather high, bulky moraine has crowded westward into the Lum channel, closing it entirely and cutting off all southward extension, unless one be found in the somewhat doubtful Rochester channel (p. 283). At its northwest end in northern Deerfield Township the Lum channel opens into the Imlay channel, and no certain indication of its course farther west has been found, though it is possible that the extra width of the Imlay channel above Columbiaville represents its continuation. The slope is northward, for railroad profiles show altitudes of 871 feet at Lum and 861 at Kings Mills and both stations are 4 or 5 feet above the channel floor. Toward its south end the floor of the channel contains much outwash, and near Kings Mills it is swampy and covered with peat.

The altitude of the highest Maumee beach at Imlay is 850 feet and near Goodland Church about 855 feet. From this it appears that the Lum channel could have served as the outlet of glacial Lake Maumee only if the land in Lapeer County stood at that time lower relatively to the land at Fort Wayne, Ind., than it did a little later during the operation of the Imlay outlet. In that event it may have become the outlet at the time of an extreme backstep in the oscillations of the ice front, and the beach made then may have been completely overridden and destroyed as far south as Birmingham by the readvance of the ice to the Birmingham moraine. It is this same Birmingham moraine that closes the Lum channel northwest of Imlay and forms the eastern boundary of the Rochester channel farther south.

Although it is not possible at present to make sure of its relations to the lake history, it seems almost certain that the Lum channel, including probably the Rochester channel as a part of the same line, marks the establishment of a full-volume discharge for Lake Maumee before the time of the Imlay outlet and during the early part of the time when the western front of the retreating Lake Huron ice lobe was oscillating back and forth across this critical area. The beach of Lake Maumee, which was the correlative of the Lum channel, has not been identified.

IMLAY OUTLET CHANNEL.

MAIN IMLAY CHANNEL.

General character.—The Imlay channel west of Lapeer County was described in connection with the glacial drainage of the eastern limb of the Saginaw lobe (p. 254). The head of the channel has generally been described as being a mile or two south of Imlay, and it was in fact there during the last stages of Lake Maumee. But when the channel was first established through eastern Lapeer County its head was 7 or 8 miles farther south, or about at Almont; and this short length of the channel, which really belongs with the moraines of the Huron-Erie slope, may as well be described here.

From Almont to North Branch the Imlay channel is bounded on the east by a moraine which, though a slender individual, is nevertheless through most of the distance quite clearly and strongly developed. It forms the immediate eastern bank of the channel throughout this interval and except in one reach between Imlay and central Goodland Township is so closely set against the channel that it seems to have been pressed forward to make the channel more narrow.

The Imlay channel begins to have a definite floor 2 miles east of Almont. The floor is swampy and contains more or less peat and marl nearly all the way from Almont to Imlay and in this interval has a width of a third to a half mile, although at the level of the highest beach of Lake Maumee it is generally a mile or more wide. North of Imlay for 4 or 5 miles the moraine stands back a little to the east, and the swampy channel floor holds a width of about one-half mile. In the central part of Goodland Township the moraine presses in again more closely than

before, and the channel continues thence to a point 2 or 3 miles southeast of North Branch with a width of one-third to one-half mile between high, steep bluffs.

The lands bordering the Imlay channel from Almont to Imlay are relatively low on both sides; except for a large knoll running a mile northeast from Almont on the west side and a narrow morainic ridge east of Imlay they nowhere exceed 30 or 40 feet. From Imlay to Mill Creek the banks on the east side continue with the same low relief, but from Mill Creek to the transverse channel south of North Branch the moraine presses up to the east side of the channel and for 8 miles forms a steep bank 70 to 80 feet high. In this interval the channel is floored at many places with gravel and sand and at some places contains small bars or terraces. The peat on the northern divide is not deeper than 3 feet. On the west side a high, rugged moraine forms a steep bank to the channel through the whole interval to North Branch. The kames described above form the highest points.

From the point where the transverse channel enters the Imlay outlet above North Branch the channel floor becomes wider and the banks somewhat lower. The floor is swampy to a point below North Branch, but through the southern part of Rich Township the banks are lower and the floor is bowldery. On leaving Rich Township the channel turns southwest and keeps this course to the county line. Except for about 1½ miles above Columbiaville, the channel in this interval is a full mile in width and is floored with sandy gravel. The gravel filling begins near the north line of Deerfield Township, reaching some distance eastward into the mouth of the Lum channel and expanding to a width of more than 2 miles just above the narrows northeast of Columbiaville. In the narrows there is not much gravel, but below Columbiaville the channel widens again to a mile, and the gravel extends to the county line and also some distance up the Elba channel. From Rich Township to the narrows the bed of the modern Flint River is trenched into the gravels about 10 feet. Below Columbiaville the gravels stand as terraces 20 to 25 feet above the river. A mile or two south of the town the terrace on the east side carries a number of basins. The heavy gravel terraces continue to Flint and Flushing.

The origin of the narrows above Columbiaville is not clear. The Imlay channel when first made probably had the average width in this interval, and the expanded portion just above the narrows suggests an obstruction introduced after the first cutting of the channel, probably by a readvance of the ice. As just stated, the wide part above the narrows may be a part of the Lum channel. There are several good-sized kames at the head of the narrows on the south side. It seems probable that some of the marked irregularities of the morainic ridges west and north of Columbiaville are due to readvances of the ice into the westward extension of the Lum channel and that the channel was overridden and obliterated by these readvances.

Between Almont and North Branch there are three low divides in the channel. One is 1½ miles north of Almont, another 3 miles north of Imlay, and the third 2 miles south of the Deanville kames. All are flat and are covered with peat and would not be noticeable, except that they divide the water in the channel and turn it into different drainage systems.

Gradient.—In order to get an adequate conception of the relation of the Imlay outlet channel to Lake Maumee it is necessary to consider to what extent the northward differential uplift has affected the channel since it was made. In the Ann Arbor quadrangle the highest Maumee beach has an altitude of 800 feet and was affected very little if any by differential uplift. But 4 or 5 miles north of Birmingham it begins to rise northward, and from the vicinity of Rochester it rises at an average rate of about a foot in a mile. This brings the beach at Almont to an altitude of 840 feet and at Imlay of about 850 feet. At Almont, therefore, the beach is 40 feet higher than it is at Birmingham, where it was not uplifted.

The floor of the Imlay channel 1½ miles east of Almont has an altitude of 796 feet. But since this is 40 feet higher than it was formerly, its altitude before deformation was about 756 feet. East of Imlay the channel floor is about 800 to 802 feet [1] and on the divide south of the Deanville kames it is about the same. At Imlay its altitude was formerly 50 feet lower than

[1] The altitude of the Huckleberry Marsh in the Imlay channel 3 miles north of Imlay is 808 feet as determined by Mr. Leverett by wye level from Imlay, but a pole can be run down there 10 feet or more in slush, so that the outlet floor is below 800 feet.

now, or 750 feet. The northern divide is about 10 miles north of Imlay, and at the same rate of rise—a little over a foot in a mile—the original altitude of that point was, say, 60 feet lower than now, or 740 feet. About 1½ miles south of North Branch the present altitude on the floor is about 785 feet, and this, measured in the northerly direction of the uplift, is about 4 miles farther, so that the floor was originally about 64 feet lower than now, or in round numbers 720 feet.

It is thus evident that the original fall of the Imlay channel was from about 756 feet at Almont to about 720 feet at North Branch, or 36 feet, whereas the present descent is only 10 or 11 feet. By the windings of the channel the distance is 24 miles, giving an original descent of about 1½ feet per mile and a present descent of less than 6 inches per mile.

These figures are based on the altitudes of railroads which cross the channel at Almont, Imlay, and North Branch and on aneroid measurements for the northern divide. They are not as accurate as could be wished, but are probably not far wrong.

This part of the Imlay channel is of exceptional interest on account of its relation to the direction of differential uplift. So far as known, none of the other outlet rivers of the glacial lakes nor any of those that ran along the edge of the ice or away from it flowed for any considerable distance toward the north; that is, up the slope of the tilted or uplifted land. Where the course of a river was along an isobase, its rate of descent was not changed by the uplift; where it was down the slope of the uplift, its rate of descent was increased; but where its course was up the slope, its rate of descent was diminished and might even be reversed. Where the uplift increased the apparent descent of the channel neither the existence of the uplift nor its general direction can be inferred safely from the channel alone. But where the descent was greatly reduced or reversed this fact and the general direction of the uplift become evident. This part of the Imlay channel is the only one known that affords a test of this effect of land tilting. The channel is strongly developed and shows abundant evidence of scour—certainly more than one would expect from a descent of 10 or 11 feet in 24 miles. From North Branch to Flushing the differential uplift increased the descent of the channel 30 to 35 feet. As it is now about 75 feet it must originally have been 40 to 45 feet in about 45 miles.

The relation of the Imlay channel and of the temporary small lakes in northern Lapeer County to Lake Maumee will be discussed later (p. 348).

Readvance of the ice.—It was stated above that a moraine which is tentatively correlated with the Fowler moraine (pp. 262, 275) appears to press westward into the Imlay channel, crowding the river against its western bank. That this is a fact seems to be strongly indicated by the manner in which a later moraine presses against this moraine, especially between North Branch and Mill Creek. Between Mill Creek and the Deanville kames the two moraines are pressed into one mass and can not be distinguished as separate individuals. Between the kames and North Branch their crests are a mile apart and are clearly separate. North of Imlay to Mill Creek they are more lightly developed and very distinctly separated. Southeastward from Imlay they are not in contact at all, but separate more and more widely toward the Macomb County line. In southwestern St. Clair and northwestern Macomb counties they show the spacing of 2 to 4 miles that characterizes the same group of moraines in the Saginaw Valley.

From these facts it seems clear that this part of the Imlay outlet was strongly affected by a readvance of the ice front and narrowly escaped being closed along the line between North Branch and Mill Creek. The pressure was greatest for about 4 miles between Mill Creek and a small brook which descends to the channel from the Deanville kames. These two morainic ridges both show clearly westward pressure or readvancing movements, the first ridge pressing against the channel and almost closing it and the second ridge pressing severely against and partly overriding the first. Yet they are separated by the usual interval east of Almont. The closing of the channel by a readvance of the ice, so narrowly escaped at the time of both of these moraines, had actually occurred at an earlier stage when a readvance closed the Lum channel. In considering questions relating to oscillations and readvances of the ice front, this group of facts connected with the Lum and Imlay channels and associated moraines is of the greatest importance.

BUTTERNUT CHANNEL.

The Butternut channel came in from the northeast as a tributary to the Imlay channel. It ran southwest along the front of the Owosso moraine and had its headwaters apparently in the vicinity of Kingston and East Dayton. In its length of about 25 miles the present channel descends 140 feet—from about 880 to 740 feet. Its course was directly down the plain of the tilted land, so that something like 30 feet must be subtracted to find its original descent of 100 to 110 feet. At its head it drained two or three small lakes, one lying southwest of Kingston and others, probably smaller, in Koylton Township and northeast of Mayville.

In the lower course of the Butternut channel, from a point about west of Otisville, prominent gravel terraces, like those of the Imlay channel, suggest a certain amount of aggradation or filling after the first or most active deepening. This and the strongly marked aggradation of the Imlay channel between Columbiaville and Flint are probably associated with a readvance of the ice front in Genesee County.

EAST DAYTON SPILLWAY.

Although the Juniata moraine is poorly developed except in two or three places, the ice front while building it appears to have formed the northern bank of a large river, known as the East Dayton spillway, which flowed toward the southwest in southern Tuscola County. Its course where it is constricted 2 or 3 miles west of East Dayton is well defined. Its present altitude at this point is about 740 feet. At an earlier stage it probably flowed at a level 30 or 40 feet higher and passed through central Fremont Township to the sandy area near Juniata.

Through Wells and Novesta townships the bowldery belt probably marks the line of its flow at the lower level. The part of the belt which comes from the southeast in Novesta Township is in all probability due to the scour of the stream without the aid of the ice front in contributing bowlders. The bowlder belt heads near Novesta, and the two arms of the long swamp of the south branch of Cass River end there. The altitude is now 775 to 780 feet and was originally 80 or 85 feet lower.

The flow of the East Dayton spillway was certainly very short lived as compared with the Imlay outlet river. The river was probably temporary and existed only during a brief halt in a relatively rapid retreat of the ice front in the transition from Lake Maumee to Lake Arkona. The spillway appears to head on the till plain of Sanilac County and is not known to be related to any beach.

NORTH BRANCH TRANSVERSE CHANNEL.

From the extreme northeast corner of Burnside Township, Lapeer County, a well-developed channel, known as the North Branch transverse channel, runs southwest and west to the Imlay channel, a mile above North Branch. It is a swampy depression of varying width down to a point about 5 miles east of North Branch, beyond which it is floored with gravel. The gravel-floored part is one-third to one-half mile wide and the bordering land rises 20 to 40 feet, but not steeply.

LAMOTTE CHANNEL.

The channel associated with the Lamotte esker is closely related to the North Branch transverse channel. From the northeast corner of Lapeer County the Lamotte swamp runs directly north along the south branch of Cass River, expanding within 3 miles to a width of 2 miles. For 6 miles farther north it contains the broken chain of the Lamotte esker. Two miles still farther north it divides into two branches of irregular width, both of which bear northwest to a point near Novesta, where they meet the east end of the bowldery belt that marks the East Dayton spillway.

The Lamotte channel was made originally by a southward-flowing subglacial stream or one flowing in an ice-walled canyon in the thin mass of dead ice which appears to have covered the till plain of Sanilac County at that time. The ice front then rested about on the Deanville and Mayville moraines, and the part of the channel which lay outside of the ice front (now constituting

the North Branch transverse channel) became an important line of glacial drainage tributary to the Imlay channel, and the stream that flowed in it appears to have deposited the gravels in its western part. Later, during the life of the East Dayton spillway, the northern part of the Lamotte channel was occupied by a stream flowing in the opposite direction (northward). This stream collected the thin sheet of water coming over the flat till plain from the east and guided it to the ice front northwest of Novesta and thence southwest through the East Dayton spillway to Lake Saginaw. If the East Dayton spillway served as an outlet for Lake Maumee its service must have been short, for it does not extend east of East Dayton, unless indeed its continuation there was obliterated by a readvance of the ice to the Juniata moraine. If it was not obliterated by readvancing ice this spillway must have received its waters from a thin sheet of water which came over the divide at the east and south but which did not last long enough to cut the channel back that far.

Thus the Lamotte channel was originally the headward, ice-bound part of the stream that flowed westward through the North Branch transverse channel. After the ice disappeared its northern part near Novesta probably became a headward northwestward-flowing tributary to the East Dayton spillway and served for a brief time as the outlet of a late stage of glacial Lake Maumee.

MORAINES OF THE HURON-ERIE SLOPE IN MICHIGAN.

By Frank B. Taylor.

GENERAL FEATURES.

The moraines of the Huron-Erie slope in Michigan lie in a belt 20 to 30 miles wide extending southwest from Port Huron and Imlay along the southeast border of Michigan for a little more than 100 miles. Imlay is on the forty-third parallel of latitude and Port Huron is 5 miles south of it. Into the north end of this district the West Branch-Gladwin group of moraines emerges after having passed through the tangle of the interlobate area. Seven or eight individuals are recognizable, but only the first or earliest and one or two later fragments are land-laid. All the rest are water-laid and faint and are traceable with certainty for only short distances.

The Portland moraine which runs past Hadley turns southeast in the central part of Lapeer County and appears to find a continuation in the Defiance moraine, which runs southeast from Belle River, a few miles west of Imlay. This correlation is not certain and may require revision later but is the best now available. Thus the Defiance moraine appears to stand as the equivalent of the earliest part of the West Branch morainic system in the interlobate and Huron-Erie districts, but not in the central part of the Saginaw basin, where there are three earlier ridges. It is considerably stronger than the average individual of the deployed group in the Saginaw Valley. The same is true of most of the moraines south and southwest of the Defiance in Ohio and Indiana, so that in its general characters it seems more nearly related to them than to the deployed group. Still, the connection in Lapeer County seems fairly clear, and the Defiance moraine is therefore treated as being equivalent to the earliest part of the West Branch morainic system on the Huron-Erie slope. It seems to be of the order of a substage, whereas the fainter set following immediately after it is of lesser rank. The relation seems to be the same as that obtaining in the Fort Wayne moraine, where the strong front ridge is followed by several weaker ones.

DISTRIBUTION OF MORAINES.

DEFIANCE MORAINE IN SOUTHEASTERN MICHIGAN.

By Frank Leverett.

COURSE AND DISTRIBUTION.

In Monograph XLI a description of the Defiance moraine as far north as the Ohio-Michigan line was given and its relations to Lake Maumee were discussed. It lies in the midst of the Maumee basin in northwestern Ohio and marks the position of the ice border during a considerable part of the life of the first Lake Maumee. The Michigan portion lies outside the limits of

Lake Maumee except in Lenawee County from the vicinity of Adrian southward. The recession of the ice from this moraine permitted the lake to extend northward to the Imlay outlet. That this moraine may mark a readvance of the ice border at least along part of its course is suggested (1) by the strength of the Maumee beach just outside the moraine near Findlay, Ohio, which seems to demand a greater expanse of water than would lie in the narrow space between the moraine and the beach; and (2) by the somewhat greater breadth of the lobe in the Maumee basin as compared with that which formed the weak ridges between this moraine and the Fort Wayne. (See pp. 168–170.) This broadening of the lobe brings the moraine very close to the neighboring outlying ridges on the periphery of the basin, though in the axis it falls some distance short.

The Defiance moraine runs northeastward from the Ohio-Michigan line past Adrian, Tecumseh, Saline, Ypsilanti, Northville, and Amy to Clinton River a few miles east of Pontiac. It has a double crest and is more or less distinctly separated into two members, with intervening till plain and gravel plain, for a few miles in the vicinity of Ann Arbor. This has led to the introduction of the terms "outer Defiance ridge" and "inner Defiance ridge" in the revised edition of the Ann Arbor folio and in the Detroit folio. The outer Defiance ridge is the "middle" moraine of the first edition of the Ann Arbor folio and the "Northville" moraine of the report on Wayne County, Mich., by W. H. Sherzer, published by the Michigan Geological Survey.

North from Clinton River the Defiance moraine is in places banked against an earlier moraine and in places separated from it by a narrow glacial drainage channel. It can be traced as far as Belle River a few miles west of Imlay, beyond which point its continuation is uncertain. Probably, however, it constitutes the outer part of a morainic system that runs northwestward from Imlay into a reentrant angle between the Huron-Erie and the Saginaw lobes north of Lapeer. If it does this, it is probably represented in the Saginaw basin by the Portland moraine and perhaps by one or two other members of the system of slender moraines between the Charlotte morainic system and the Port Huron morainic system.

TOPOGRAPHY.

The moraine rises from about 800 feet above sea level in the vicinity of the Ohio-Michigan State line to 1,000 feet on the highest points in northeastern Oakland, northwestern Macomb, and eastern Lapeer counties. In all these counties portions of it rise but little above 900 feet, so that the general rise in the Michigan part is but little more than 100 feet.

Near the State line of Ohio and Michigan the moraine changes from a very smooth water-laid ridge to a gently undulating land-laid moraine. In places two or more ridges are recognizable, but as a rule the crest line is single. At Adrian two ridges of about equal strength are present, but between Adrian and Ypsilanti wherever two ridges are present the outer or western is much stronger than the inner or eastern. Portions of the inner ridge in the vicinity of Ypsilanti are below the level of Lake Maumee, and in southern Washtenaw County its crest almost coincides with the highest beach of Lake Maumee. From the State line northeastward to Clinton River the surface of the ridge is gently undulating and is characterized in places by numerous basins, especially in the Ann Arbor quadrangle west of Ypsilanti. From Clinton River northward to southern Lapeer County large kames 75 to 100 feet or more in height are distributed along the moraine and stand in striking contrast with the gently undulating portion farther south.

STRUCTURE OF THE DRIFT.

Along much of its course the moraine is clayey, though many of its small knolls are composed in part of sand or gravel, and gravel is present in large amounts in the kames north of Clinton River. The moraine is in places coated with a sandy deposit due probably to flooded conditions of the country immediately outside the moraine, for the ice was banked against a slope which gathered waters from higher land to the west as well as from the melting of the ice. These sandy deposits are conspicuous in the vicinity of Saline River in southern Washtenaw County and northeastward from there to Ypsilanti. There is also considerable sand in the vicinity of the State line on both the Ohio and the Michigan sides.

OUTER BORDER DRAINAGE.

The flooded condition on the outer border of the moraine just noted is conspicuous only south of the latitude of Ypsilanti. Northward from that city as far as Clinton River there is a channel which appears to have had a southwestward-flowing current of water that was strong enough in parts of its course to carry gravel of medium coarseness. In other parts pools existed, and these are coated only with sand or fine material. It is probable that at the time of the development of this moraine a small lake occupied a basin around Lapeer (see pp. 273, 274); its correlation with this morainic system depends on the course of the Defiance moraine through Lapeer County.

BIRMINGHAM MORAINE.

By Frank B. Taylor.

COURSE AND DISTRIBUTION.

The Birmingham moraine appears to correspond to the Lyons moraine of the Saginaw lobe. It is strongly developed from north-central Lapeer County down to the north bank of Belle River, a mile north and west of Imlay, but from Belle River to Romeo it is weak. Just north of Belle River and 1½ miles west of Imlay morainic masses of considerable height, apparently belonging to this moraine, appear to have pushed westward and closed the Lum channel.

In the stretch of 2 or 3 miles west and southwest from Imlay there is nothing that seems distinctly morainic. The surface is smooth with only the faintest suggestion of undulation or ridging, but it is rather plentifully covered with bowlders. North and south through the central part of this small plain area a belt nearly a mile wide, bearing almost no bowlders, is smoother and flatter than the ground on either side of it. This strip is believed to mark the interval between the Defiance and Birmingham moraines, the faintly undulating bowldery belt west of it corresponding to the Defiance moraine and the narrow strip east of it to the Birmingham moraine.

The interval of 5 or 6 miles between Mill Creek northwest of Imlay and the south edge of this bowldery plain is the only place where clear separation between the two moraines is lacking. At the south edge of this plain a small tributary of Belle River flows eastward, crossing the two moraines in sec. 36, Attica Township, and secs. 31 and 32, Imlay Township.

In secs. 36 and 31 a small but well-defined glacial river bed, the Almont channel, comes from the northwest out of the flat area in the west-central part of Attica Township. This drainage line is small but is remarkable for the persistence with which it keeps its way along the west side of the belt of low bowldery knolls and gravel deposits which represent the Birmingham moraine from Imlay to Romeo. It is sinuous, especially between the southeast corner of Attica Township and Almont, but it is not broken or interrupted. It is well developed at the western edge of Almont and near the county line 4 miles south.

It seems necessary to mention this channel in advance of the discussion of the glacial drainage of this district, because it is this drainage line more than anything else that makes certain the continuity of the faint moraine between Imlay and Romeo. In the interval between the southeast corner of Attica Township and Romeo—a distance of 12 or 13 miles along the channel—there are not less than 10 gaps in the low moraine to the east through which this stream would certainly have flowed to the lower ground of the Imlay channel and Clinton River if they had not been closed by the solid ice that was then resting on the moraine. It may be observed also that a considerable part of the Birmingham moraine in this interval of weak development lies below or east of the highest or first Maumee beach. From these considerations it is clear that however weak and slender the Birmingham moraine appears to be in the interval between Imlay and Romeo, it is nevertheless present and may be depended on in the correlation of moraines, ice movements, and glacial drainage in this vicinity. In this interval of faint development there is only one prominent knoll to mark its course, and this lies obliquely, extending 1½ miles northeast from Almont. The reason for the faintness of the Birmingham moraine in this interval will be discussed to better advantage in connection with the glacial drainage (pp. 283–284).

At Romeo the 400 or 500 yard Almont channel passes into the mile-wide Rochester channel west or in front of the strong, high morainic ridge which begins at Romeo and extends south-southwestward, past Rochester and Birmingham, opening out at the latter place upon the lake plain below the highest beach of Lake Maumee.

The Birmingham moraine from Romeo to a point about 3 miles northeast of Rochester is a high, relatively narrow ridge of bowlder clay and is in fact one of the most sharply developed and clearly defined terminal moraines in this region.[1] Beyond this point the strongly developed ridge ends and is replaced by a small till plain, and where the moraine reappears south of the Clinton River it is relatively low and smooth. South of sec. 22, Avon Township, Oakland County, to Birmingham its crest steadily falls, gradually losing its expression as a land-laid moraine. It continues, however, 6 or 7 miles southwest from Birmingham as a low, smooth swell which controls the course of Rouge River. At Birmingham it merges with the north end of a much broader low ridge, probably interlobate in character, which runs southeastward directly down the slope to Detroit and thence southeastward nearly to the shore of Lake Erie at Leamington, Ontario. The continuation of its Lake Erie correlative in Wayne and Monroe counties as a water-laid moraine[2] and bowldery strip will be discussed later (pp. 287–289).

TOPOGRAPHY.

ALTITUDE AND RELIEF.

At Imlay the Birmingham moraine, or rather the bowldery strip which represents its faint development, has an altitude of 860 to 880 feet. Thence southward to Almont it declines at about the same rate as the highest beach of Lake Maumee, and in the south part of Almont it has an altitude of about 845 feet. Only the large knoll northeast of the village rises much above the beach, attaining an altitude of 865 to 870 feet. From Almont south to Clinton River north of Romeo the moraine is very low, being in places slightly above the level of the beach and in places slightly below it. The altitude of the beach at Romeo is about 830 feet.

At Romeo the moraine suddenly becomes strongly developed, though not more than 1½ miles wide, and continues so to a point 3 miles northeast of Rochester, its crest rising in several places above 900 feet and having an average elevation of about 870 feet. A till plain of about a square mile with an altitude of 760 to 780 feet there takes the place of the moraine. South of Rochester in a small area in sec. 22, Avon Township, the crest rises to an altitude a little above 860 feet; beyond, it declines steadily at the rate of about 10 feet to the mile to an altitude of 780 feet at Birmingham.

From Imlay to Romeo the Birmingham moraine has extremely slight relief, few of its knolls rising more than 10 or 15 feet above the adjacent ground. At Romeo and southward it has a steep slope on both its sides and rises 60 to 100 feet above its base. South of Rochester it has a relief of 60 or 70 feet, but declines rapidly toward Birmingham.

CHARACTER.

From Imlay to Romeo the moraine generally consists of low bowldery knolls, with some small kames and gravel ridges. For much of the distance the crest is only a little above the highest beach of Lake Maumee, and toward Romeo it at some places passes below the beach level, the beach appearing only on small islands.

From Romeo to Rochester the strong moraine has a swell and sag topography, with some basins where its slopes have not been subsequently modified. Its eastern slope, however, was heavily undercut after it was made and has since been deeply gashed with ravines. For 3 or 4 miles south of Rochester the ridge has a faint swell and sag expression, but within a short distance farther south it becomes smooth and devoid of notable surface features.

[1] See Rochester topographic sheet of the U. S. Geol. Survey.

[2] In 1913 Leverett and Sherzer found evidence of the continuation of the moraine in water-laid form along the east side of Rouge River to the Wayne County line. There are slight undulations on its southeastern or inner slope, and the relief on that side is in places easily perceptible to the eye, being 15 feet or more in half a mile.

STRUCTURE OF THE DRIFT.

From Imlay to Romeo the moraine is generally bowldery on the surface, but is composed largely of clay beneath, though it comprises several gravel deposits in the form of kames, the most notable ones being in secs. 33 and 34, Imlay Township, and sec. 35, Almont Township, and several smaller ones between Almont and Romeo. The strong ridge back of Romeo is composed mainly of stony clay but has kames and much sandy outwash along its west front in the northern part of Washington Township. Southward from Rochester the ridge is composed more generally of clay.

GLACIAL DRAINAGE.

As nearly all the moraines of the Huron-Erie slope in Michigan are water-laid, there is relatively little ice-border drainage to discuss. Mr. Leverett has described that associated with the Defiance moraine farther south (p. 281), and the writer has discussed the relation of the Imlay outlet to the moraines that border upon it (p. 277). What remains is mainly drainage associated with the Birmingham moraine.

ALMONT CHANNEL.

As Mr. Leverett has pointed out, the Defiance moraine pressed against the earlier deposits in the vicinity of Amy, 4 or 5 miles east of Pontiac, and interfered with the southward drainage from the interlobate angle in Lapeer County. This interference led to the development of a line of glacial drainage that went northward through eastern Dryden Township, Lapeer County, turning northwestward a mile northeast of Dryden. The channel is very plain in southern Attica Township, where two or three branches follow narrow courses between high morainic knolls.

A small, narrow channel, known as the Almont channel, opens out of the eastern branch in a nearly reverse direction or a little south of east. It is commonly not over 400 or 500 feet wide and to Almont is rather crooked. Its course and character and relations as far as Romeo have already been described (p. 281). West of Romeo it passes into the broad Rochester channel, which lies in front of the strongly developed part of the Birmingham moraine, but for 4 or 5 miles it keeps in its narrow bed, with the outwash rising 40 to 50 feet above it; finally it loses its identity in a swamp in the southwest part of Washington Township, Macomb County.

At its head in sec. 26, Attica Township, Lapeer County, the altitude of the Almont channel is 880 or 890 feet, at Almont about 830 feet, west of Romeo about 810 feet, and in southwestern Washington Township 800 feet. Its length is about 20 miles and its descent 80 to 90 feet. Allowing for subsequent tilting of the land, its original descent was 60 to 70 feet, for the river flowed toward the south.

ROCHESTER CHANNEL.

A valley about a mile wide begins about 2 miles west of Romeo and extends southwest along the west or front side of the strongly developed part of the Birmingham moraine to Birmingham. A mile or two southwest of the latter place it opens out onto the eastward slope of the old lake bottom below the highest beach of Lake Maumee. Throughout its 20 miles of length it maintains a constant relation to the Birmingham moraine. Its character and relations strongly suggest that it is a fragment of a large glacial drainage channel, and it is here termed the Rochester channel.

Its connections and relations to other drainage, however, are obscure, its greatest peculiarity being its abrupt termination at its north end, where it is 1½ miles wide and where, except for its narrow entrance, it is surrounded on the east, west, and north by morainic deposits that rise 100 feet or more above it. The sandy and gravelly deposits on its floor are not smoothly laid, like the floors of most drainage channels, but show considerable irregularity. For 4 or 5 miles from the north end it is filled with sandy outwash from the Birmingham moraine to a level of 840 to 860 feet, which is considerably higher than its general level farther south. Between Rochester and Birmingham it is again filled with a wide flat deposit of outwash up to 810 to 815 feet. Near its north end it has swampy areas, which lie below 800 feet and which seem to be original depressions not scoured out by a river. Nevertheless, it seems much like the channel

of a great river, and it is tentatively suggested as the possible correlative of the Lum channel 20 miles farther north.

Certain facts strongly suggest this possibility. In the first place, both the Rochester and the Lum channels lie close against the front of the Birmingham moraine, and it seems clear that if this moraine had drawn back a little from its present position between Romeo and Lum it would have permitted a continuous open passage between the two places.

In the second place the weak and greatly modified part of the Birmingham moraine lies just in the interval between the north end of the Rochester channel and the south end of the Lum channel, as might be expected if the channel had been closed in this interval by a readvance of the ice. The facts are so simple that it seems impossible to doubt the reality of this event.

But if these channels are related in this way the altitudes of their floors are such that it would be necessary to suppose that the land around the Lum channel stood somewhat lower with reference to the Fort Wayne outlet than it did later at the time of the Imlay outlet, and hence that after the Lum channel was closed and before the Imlay was opened there was a slight elevation of that region. That such an elevation took place is not inconsistent with the later history of this district.

Regarding the Rochester-Lum channel as a former outlet of Lake Maumee, it may be noted that its head was near Birmingham and that if allowance is made for the later sandy outwash that covers the channel floor between Rochester and Birmingham the head appears not to have been measurably affected by this early uplift, for the channel still stands in normal relations to the highest beach of Lake Maumee at Birmingham. It appears to follow that the uplift which elevated the Lum section before the opening of the Imlay channel did not affect the land at Birmingham; nor, so far as indicated by the highest beach of Lake Maumee, did it affect any of the lands bordering on this lake farther south.

When compared with other parts of the shore the inner slope of the moraine between Rochester and Romeo appears to be steepened more than would be expected from wave action, and from this it is inferred that as the ice front drew back from the Birmingham moraine the waters of Lake Maumee rushed northward through a narrow passage between the ice and the inner side of the moraine and cut away the base of the latter. At Romeo the middle beach of Lake Maumee runs along the crest of a small, narrow morainic ridge—apparently the last stand of the ice during the building of the Birmingham moraine. Between this and the high moraine there is a trough one-fourth mile wide which seems to have been scoured out when the ice stood at the position of the middle beach. These two features are distinctly developed in the south part of the village of Romeo. Later, when the ice had withdrawn eastward the waves of the lake at the level of the first or highest beach made a shore line along the base of the hill a few feet above this channel floor. The inner slope south of Rochester is not steepened in this way.

WATER-LAID MORAINES AND BOWLDERY STRIPS.

The water-laid moraines and bowldery strips are less definite than the land-laid ones, and their correlations are more or less uncertain. It is thought best, however, to describe briefly such of their features as seem to throw light on the recession of the ice sheet from the southeastern part of Michigan. There is more room for difference of opinion here than there is in regard to the well-defined glacial features, and much that is here presented must be regarded as tentative.

DETROIT INTERLOBATE MORAINE.

The broad, smooth ridge running directly down the slope from Birmingham to Detroit (p. 292; also fig. 13, p. 485) is not to be regarded as the normal continuation of the Birmingham moraine, for such an assumption would involve a violation of the fundamental principles of the adjustment of a semiplastic ice mass to topography and of the law governing liquid or semiliquid bodies moving on the line of least resistance under the force of gravity.

The Birmingham moraine appears to continue southwestward beyond Birmingham as a bowldery strip with the same normal altitude relation that it has between Romeo and Birming-

ham, gradually declining in that direction. The broad, low ridge between Birmingham and Detroit runs directly down the slope, almost at right angles to the normal trend of the Birmingham moraine. This seems to suggest that the Detroit ridge is not a terminal moraine in the ordinary sense but is an interlobate moraine marking the line of contact between the Lake Huron ice lobe coming from the northeast and an extension of the main Lake Erie lobe to the north and northwest.

This inference is strongly supported by glacial striæ, which were found by Sherzer [1] to run north-northwest, in the Sibley limestone quarries north of Trenton, and by a number of other northwest-pointing striæ at Stony Point and Monroe (p. 290). It is also supported by the transportation of bowlders from Lake Erie northwestward to the vicinity of Ypsilanti and Ann Arbor. It seems probable, therefore, that the Detroit ridge is a subglacial, partly water-laid, interlobate moraine; that is to say, that it was formed along the line of contact between the Huron and Erie ice lobes, but mainly under the ice and below the then existing level of the lake. It follows that southwest of Birmingham the ice front was probably standing on or not far from the normal line of continuation of the Birmingham moraine.

IMLAY MORAINE.[2]

The northern part of the Imlay moraine has been briefly noted as a probable partial correlative of the Fowler moraine (p. 241). Only one short, narrow piece of the Imlay moraine forming the east bank of the channel east of Imlay rises above the level of the first beach of Lake Maumee. It is a stony till ridge about a quarter of a mile in width and 870 feet in altitude. From this place the moraine is developed northward along the east side of the Imlay outlet and also runs south-southeast close along the east side of the Imlay channel to a point east of Almont, and then in fading form, marked mainly by a bowlder belt, it continues southward along the east side of Clinton River nearly to Romeo. A mile or two northeast of Romeo it appears to be represented by a thin, flat sheet of stony till, overlying gravel beds. This is the farthest point south to which it has been continuously traced. South of the small till ridge opposite Imlay the moraine is all water-laid and passes southward deeper and deeper under the level of the first Maumee beach.

East of Romeo and farther south a strongly marked bowldery belt covers much of the vertical interval between the Maumee and Whittlesey beaches. The bowlders probably represent the Imlay moraine in large part but scarcely suffice to fix its course definitely. Farther south a single group of distinctly morainic knolls that seem likely to belong to this moraine is found in Troy Township, Oakland County, 3 or 4 miles east and northeast of Birmingham. These knolls, which are composed of stony till and are 5 to 12 feet high, are the more noticeable because they stand on a slope which, except for beach ridges, is smooth.

GOODLAND MORAINE.

On the forty-third parallel the narrow, smooth ridge of the Goodland moraine lies a mile east of the Imlay moraine, from which it is separated by a swamp. Half a mile east of the Goodland moraine another swamp stretches away to the east, north, and south. The moraine bends gradually southeast and runs past Smith station for about a mile beyond the line of Armada Township, Macomb County. Throughout the whole distance it is a low, smooth ridge, apparently water-laid, rising 10 to 25 feet above the adjacent till plains, and a quarter of a mile to a mile wide. The Goodland moraine was not certainly traced farther, but it seems probable that it turns south in sec. 3, Armada Township, and causes the southward bulge in the Whittlesey beach 2 miles southwest of Armada. Just below the Whittlesey beach a bowldery area bearing some low stony knolls probably belongs to the Goodland moraine, but farther south nothing was seen that could be certainly identified with it. From a mile south of Belle River to its end in Armada Township it is surmounted with gravelly beach bars of Lake Maumee.

[1] Sherzer, W. H., Ice work in southeastern Michigan: Jour. Geology, vol. 10, pp. 194-216.

[2] This moraine and the Goodland moraine, regarded as one individual, were formerly described as the Toledo moraine (Bull. Geol. Soc. America, vol. 8, 1897, p. 39).

BERVILLE MORAINE.

Another slender water-laid moraine, called the Berville, has not been certainly identified with any of the moraines farther north. It is best developed between Belle River and a point in sec. 7, Richmond Township, Macomb County. It is of about the same strength and character as the Goodland moraine, rising 10 to 25 feet above the adjacent lands, and like it is surmounted by bars of Lake Maumee. Its course beyond sec. 7, Richmond Township, is not clear, but, as the ice front generally fitted itself to topography and as moraines in a country as smooth as this tend to be nearly parallel, it is thought that it turns south or perhaps a little west of south. A mile and a half southeast of Armada a very bowldery tract below the level of the Whittlesey beach lies in the line of the moraine if the latter turns southward, but neither this nor anything else in that direction was certainly identified with it.

Northwestward from the hamlet of Belle River the Berville moraine is continued up to the great transverse stony ridge which runs southwest through Mussey Township, and it probably includes some knolls that stand a mile farther west. Its identity farther north was not made out. Its relation to the Goodland and Imlay moraines suggests that it may belong to the Otisville moraine, which runs southeast from Clifford.

MOUNT CLEMENS MORAINE.

A faint water-laid moraine, the Mount Clemens, has been identified as far north as northwestern St. Clair County. It runs southeast through secs. 14, 13, and 24, Mussey Township, and 19, 30, 31, and 32, Emmett Township, and thence directly southeast to a point about 2 miles north of Memphis. In secs. 15 and 16, Riley Township, a transverse kame or short esker marks the place of this ridge, which is there very faint but which appears to turn south past Memphis and becomes quite prominent just west of the Whittlesey beach about halfway between Memphis and Richmond, where it has almost the relief and expression of a land-laid moraine.

Southwest of Richmond the slope below the Whittlesey beach is rather stony; two or three miles to the southwest low stony knolls begin and a broad ridge runs directly south past New Haven, Chesterfield, and Mount Clemens, and on southwest to the south line of Macomb County north of Detroit. Near the county line it broadens and fades out as a perceptible ridge, but in all probability continues southward into the city of Detroit and merges into the Detroit interlobate moraine.

From a point 3 or 4 miles north of New Haven to a point nearly 10 miles southwest of Mount Clemens the moraine is well developed. It is this ridge which produces the remarkable concentration of the numerous headward branches of Clinton River into one trunk stream at Mount Clemens. There are no other gaps in the moraine where streams could pass through. For a moraine deposited in water nearly 200 feet deep it is remarkably strong and definite in its development.[1]

EMMETT MORAINE.

The Emmett moraine, so far as yet identified, has its northern end in northwestern St. Clair County, in sec. 12, Mussey Township, and runs southeast, passing a mile west of Emmett. Near Emmett it is fairly strong, but elsewhere it is very weak. It was not definitely recognized farther southeast, but it probably coincides with the Whittlesey beach toward the southeast a mile north of Lamb. Beyond this it is indicated only by an ill-defined stony belt. It is probably this moraine that gives Belle River its sharp turn just west of Columbus. From Columbus to a point west of Casco it is broken by a gap of about 4 miles, but it is probably continued near New Baltimore by a low ridge of bowldery clay. A mile and a half west of New Baltimore it ends as though cut away by wave action, rising 30 to 35 feet above the plain. Although it does not appear farther on as a ridge, it probably deflects the lower part of Salt Creek to a little west of south.

[1] In a former publication (Bull. Geol. Soc. America, vol. 8, 1897, p. 39) the writer called this same ridge the Detroit moraine. It was not seen until later that the broad ridge which passes through Detroit is interlobate in character and extends directly up the slope to Birmingham.

The United States Lake Survey chart of Lake St. Clair shows some interesting features which are thought to have connection with this moraine. Just outside the head of Detroit River the villages of Grossepoint and Claireview are situated on a well-defined ridge of bowldery till, evidently a terminal moraine, about a mile wide and 2 or 3 miles long. The shore along its front is thickly strewn with bowlders. At one place on its western edge the ridge rises to an altitude of 620 feet, or about 45 feet above Lake St. Clair. Northward to Milk River Point this ridge dies down and disappears, but it is shown by the chart of Lake St. Clair to be continued as a low, submerged ridge running north for 5 or 6 miles, and then to reappear as stony till in the land that projects like a delta of Clinton River below Mount Clemens. All of these features are precisely in line with the ridge back of New Baltimore, and may reasonably be regarded tentatively as parts of the Emmett moraine. The small bowldery knoll at Windmill Point, in the east part of Detroit, probably also belongs to this moraine. Beyond this, however, nothing that could be identified with it was observed. In all probability it merges into the Detroit interlobate moraine on the Canadian side of Detroit River.

ADAIR MORAINE.

Northwest of Avoca the Yale moraine is a strong and apparently land-laid deposit, but south of this latitude it has not been definitely recognized. If it continues its trend from the region of strong development it might be expected to run southeast close to Pine River—perhaps on the east side—to the western part of Kimball Township and to curve thence slightly west of south in conformity with the other moraines. Its continuation may be found in a bowlder belt, known as the Adair moraine, running a little east of north from a point near the shore of Lake St. Clair about a mile northeast of Fair Haven and passing a little east of Adair to the bank of Pine River in sec. 16, St. Clair Township. In some places it is a low ridge with a relief of a few feet, but in most places its relief is scarcely perceptible. Its course is marked nearly everywhere by a moderate number of bowlders and by bowlder clay bordered on both sides, but particularly on the east, by a formation that is without bowlders and is largely composed of lake clay. If the lake clays along the south part of the belt were removed it seems quite probable that the bowlder belt would stand out as a perceptible ridge.

The United States Lake Survey chart of Lake St. Clair shows nothing in the bed of the lake that could be correlated with this moraine, but an exposure of bowldery till and a low knoll at Stony Point on the south side of Lake St. Clair, 20 miles east of the head of Detroit River, may belong to it.

TRANSVERSE RIDGES.

Two of the transverse ridges that run southwest across the forty-third parallel in southwestern Mussey Township, St. Clair County (p. 266), appear to fade away in a swamp at the county line in secs. 30 and 31. They may, however, be continued in a remarkably bowldery tract that appears where Belle River breaks through the Imlay moraine in sec. 34, Imlay Township. Eskers and ridges such as these are liable to be slightly displaced in passing from one moraine to another. This bowldery tract is only a little north of the direct trend of the ridges in Mussey Township, and it seems probable that it is related to these ridges, which also carry large numbers of bowlders.

BOWLDER BELTS AND SANDY PLAINS OF MONROE AND WAYNE COUNTIES.

Except the low ridge extending 6 or 7 miles southwest from Birmingham, no terminal moraines have been made out with certainty southwest from the Detroit interlobate moraine. Sherzer[1] has found three bowldery belts which he regards tentatively as representing the course of the ice border. These belts are partly concealed and in this way are broken into several detached fragments by the heavy sand belts which cross the region on rather irregular lines.

[1] Sherzer, W. H., Geological report of Wayne County, Michigan Geol. and Biol. Survey, 1911, with large colored map showing surface features; Geological report of Monroe County, 1900, map; Detroit folio, Geol. Atlas U. S., U. S. Geol. Survey (in preparation). See also Leverett, Frank, Surface geology and agricultural conditions in the southern peninsula of Michigan, Michigan Geol. and Biol. Survey, 1912, map.

Sherzer's Rawsonville bowlder belt enters Wayne County north of Livonia and runs southwest, passing 2 miles west of Livonia, 2 miles east of Plymouth, and 2 miles east of Denton, and comes down to Huron River at Bellville. It turns west up the river and after passing Rawsonville turns toward the southwest but has not yet been traced more than 3 or 4 miles into Washtenaw County. The course and topographic relations of this belt suggest that it is in some sense a continuation of the Birmingham moraine.

Sherzer's Scofield bowlder belt enters Wayne County northeast of Livonia, passes a mile east of Livonia and Wayne, and crosses Huron River north of Waltz station. Here it turns southwest and passes out of Monroe County west of Ottawa Lake. From the north line of Wayne County this belt descends about 60 feet to Huron River, showing a much greater variation in altitude than is found in any beach in this area. In its course southwest from Huron River it passes Scofield and Maybee in Monroe County and is buried under the heavy sand belt a mile southeast of Ida. According to Sherzer, its presumed continuation emerges from under the sand belt in sec. 28, Summerfield Township, and winds across the southeast corner of Lenawee County into Ohio. On this course it rises from about 625 feet at Huron River to over 700 feet near the west line of Monroe County. This belt may continue to Sylvania, Ohio, and be represented by a low till ridge which runs southwest from that place and controls drainage.

The part of this belt north of Huron River was observed by the writer some years ago and was regarded as a southward continuation of a moraine then called the Toledo moraine.[1]

A third belt, called by Sherzer the Grosse Isle bowlder belt, runs along the shore of Lake Erie back of the marshes. The part between Monroe and the mouth of Detroit River is regarded by Sherzer as a continuation of a moraine that crosses Grosse Isle. Its position in this part may mark a halting place of the margin of the Lake Erie lobe, but its presumed continuation runs southwest from Monroe, rising more than 100 feet to a point a few miles beyond the Ohio-Michigan State line. Such a course seems unnatural for a marginal moraine or for any equivalent of such a moraine of either the Huron or the Erie ice lobes. The medial axis of the Erie lobe at the time of the Defiance moraine passed about through Toledo, and the Grosse Isle bowlder belt passes only 12 miles northwest of Toledo in a course nearly parallel with the axis. These discrepancies suggest either that this bowlder belt is not the equivalent of a terminal moraine, or else that the parts separated by the heavy sand belt have not been rightly connected.

These bowlder belts show certain characters and relations that led Mr. Leverett and the writer to regard them at first as possible shore lines. The bowlders lie on till and in many places in front of a low bluff or elevation, from the edge of which a more or less extensive and irregular area of fine sand extends westward. Such an arrangement suggests a sandy beach with a bowlder pavement before it. But this combination of features is not everywhere present, and the wide vertical variation of the principal belts seems to preclude the idea of their being shore lines, especially in this area, where all the clearly identified beaches are substantially horizontal.

It is a singular fact that the northern part of each belt is so related to topography that it would seem to be a normal extension from the northeast of some one of the water-laid moraines, while (if the assumed connections are accepted) the southern part of each changes its direction and trend to an upslope course, which is abnormal for a marginal moraine.

In some respects the southern parts of the belts bear a slight resemblance to the transverse ridges of Sanilac County (p. 266). But another possible explanation may be nearer the truth, though it has not yet been fully developed and may apply only to the Grosse Isle belt.

At the maximum of the ice extension the Erie and Huron ice lobes were intimately united, forming substantially one solid lobe covering the lowland between the two basins. It is probable, however, that even at the maximum there was a slight depression or crease along the line of junction between them. As the ice sheet retreated in the basins of Lakes Erie and Huron and from the high ground south of Georgian Bay the tendency of the two ice lobes to separate and become distinct bodies became more and more pronounced. In his work on the glacial deposits of the southwestern peninsula of Ontario it has been found by the present writer that, although the highland south of Georgian Bay was completely overtopped during

[1] Equivalent to the Imlay and Goodland moraines described on pp. 263-285.

the maximum of the ice, its south-central part was uncovered and became a flat insular area in the ice field, while the two lobes were still intimately united for nearly 200 miles southwest from London. This is called Ontario Island and was at first about 70 or 80 miles long and 10 to 20 miles wide.[1] It seems certain that at this stage of retreat the two lobes, though still united, were differentiated by a depression or crease on the surface of the ice along the line of contact. If any drainage escaped from the area of the island it must have followed this crease southwestward, and if the river thus produced carried sediment it would naturally be deposited where the crease came out to the edge of the lobe.

In Fulton County, Ohio, sand is distributed over a large part of the Defiance moraine. This deposit may have been made by the river just noted, and if there was any tendency to subglacial concentration of drift along its line the result may have been a bowlder belt like those here discussed. The relations observed may be accidental, but the Grosse Isle bowlder belt seems to lead up the slope directly to the sand deposit in Fulton County and its course produced toward the northeast carries it back toward London.[2] The relations of the belts, however, have not been fully worked out and their origin is still problematic.[3]

GROSSE ISLE MORAINE.

On the central part of Grosse Isle the till is thicker and stands slightly higher than at either its northern or southern ends and it is also somewhat more bowldery than the general surface of the region. The same bowldery drift belt extends a few miles southwest from Trenton and seems to find continuation in the bowlder belt described by Sherzer. This part is also marked by well-defined undulations of the surface which are possibly original morainic features, as maintained by Sherzer, but which seem to the writer to be due largely to the scour of early temporary distributaries of Detroit River. (See pp. 487–489.)

Where best developed, southwest of Trenton, the ridges are transverse to the course of the moraine and in the whole area the troughs follow the general slope of the surface, curving around from southwestward courses northwest of Trenton to southeastward courses southwest of Trenton. On the Canadian side a well-defined bowlder belt runs west from the high knoll west of Leamington, passing north of Kingsville and Harrow and trending toward Amherstburg; but it has not been traced across the intervening space. The general relations of the topography to the basin of Lake Erie from which the ice came suggest that this is the normal course of the ice margin from Grosse Isle eastward.

PRE-WISCONSIN TILL.

Till older than that deposited by the Wisconsin ice sheet seems to underlie more or less continuously all of the later or Wisconsin drift in Indiana and the southern peninsula of Michigan. It is generally darker in color than the newer drift, is more stony, and is considerably indurated. It is the hardpan of the well drillers and in places is overlain by an old soil bed or by a bed of decayed ferruginous gravel. In typical occurrences it shows much oxidation along its cracks and joints, the oxidized part appearing as bands of brown next to the cracks and in places extending many feet down into the deposit. All of these characters are not likely to be seen at any one locality, however, for at many places the Wisconsin ice sheet scoured away the old soil and the upper part of the older deposit; and the part remaining may be only the deeper part and may show little or no oxidation along its joints. The dark color and the hardness, however, are generally characteristic. The greater number of stones and their more general striation also serve to identify the older till.

[1] The development of Ontario Island is described in a paper by the writer entitled "The moraine systems of southwestern Ontario" (Trans. Canadian Inst., vol. 10, 1913, pp. 1-23).

[2] Sherzer's statement (Geological report on Wayne County, footnote at bottom of p. 82) that this explanation is suggested by the writer for all of the bowlder belts arises from a misunderstanding. The explanation was intended to apply only to the belt which extends southwest from Grosse Isle toward the great sand deposit in Fulton County, Ohio.

[3] An abstract of a paper on the Crease River was given by the writer before the Association of American Geographers at Baltimore in January, 1910.

Along the shore of the "thumb" the older till begins to outcrop about 6 miles north of Lexington. The exposure here is small, but it evidently passes below lake level to a considerable distance. Along the shore 2 miles north of Richmondville it appears in greater thickness and is typical in color, hardness, and content of striated stones, and in the firm manner in which the stones are held, even after the till around them has been largely removed. (See Pl. XII, *A, B.*) It is almost as resistant to wave erosion as the shale that outcrops on the same shore but is cut into deeply along its joints. (See Pl. XII, *A.*)

On the shore at Forestville a nearly vertical cliff about 50 feet high consists of old till and a few feet of pebbleless lake clay of the finest texture, known locally as "polish." This lake clay appears to belong with the older till and not with the newer till above.

At Croswell the older till is exposed in the banks and bed of Black River. At the west end of the bridge south of the village it forms a rocklike wall, and a little farther south it is overlain by ferruginous gravels. It may be seen along the banks of Black River for many miles below Croswell. West of Amadore over 30 feet of it is exposed in the west bank of the river.

As already noted (p. 261), it is exposed in a number of places in Tuscola County and appears in most well borings with a thickness of about 100 feet. West of East Dayton its surface is exposed in the base of the hill, where it gives rise to a wet belt or line of springs.

A mile and a half south of Avoca the old till with a distinct old soil at its top is well exposed in the north bank of Mill Creek beneath 28 to 30 feet of the newer till. (See Pl. XIII, *A.*)

STRIÆ.

The greater part of southeastern Michigan is deeply covered with drift and has few exposures of bedrock. On this account, mainly, glacial striæ have been found in very few places. Partly, however, their lack is due to the fact that shales of the softness of those in this region seldom retain striæ, the principal rocks on which they are recorded being limestone and less commonly sandstone.

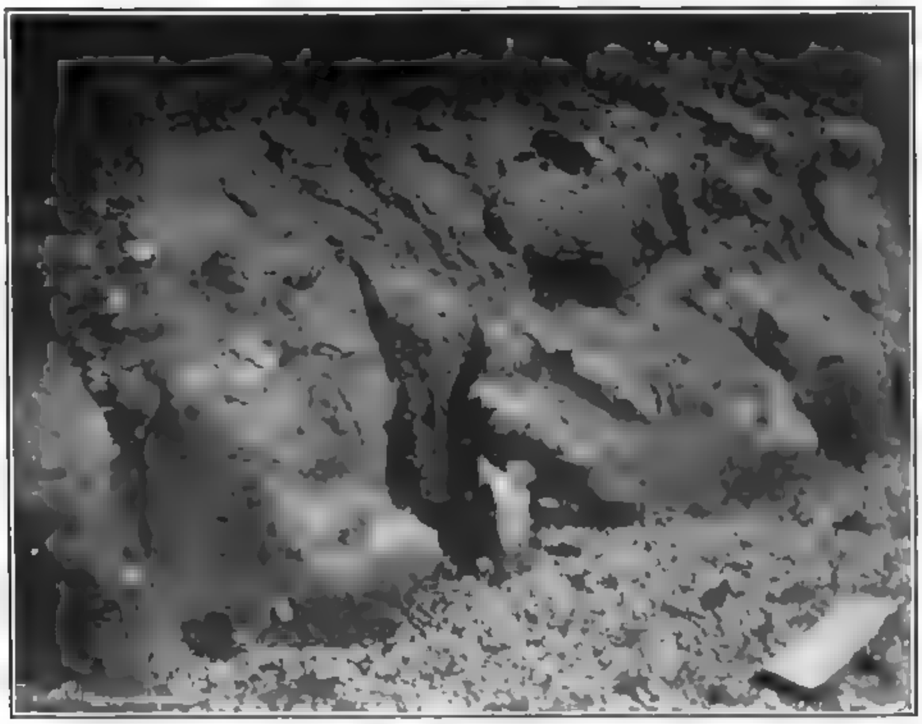
There are finely developed striæ and groovings at the Sibley limestone quarry a mile north of Trenton, and Sherzer reports striæ at several other places in Monroe County.[1] In the Sibley quarry Sherzer distinguishes three sets of striæ and a few broad, shallow troughs which he ascribes to an ice movement earlier than any of those that produced the striæ. In one of the principal troughs he finds the striæ related in such a way as to show in his opinion their relative age or order of making. He concludes that they indicate two ice invasions from the Labrador center. To the writer it seems probable that all the striæ at the Sibley quarry were made by the last ice invasion, but that the troughs are probably older.[2] The rock ledges near Trenton stood as a reef in the axis of flow of the Lake Huron ice lobe during the maximum of the last ice sheet and during a considerable time before and after the maximum, or so long as the ice from the Lake Huron basin pressed southward some distance beyond Trenton. The troughs, however, may not be due wholly to ice work. Still, the position of the Trenton ledge with reference to ice flow from the basin of Lake Huron and of the troughs running back from the struck edge of the ledge is exactly like that on Kellys Island, in Lake Erie, with reference to the ice flow in that basin; and the troughs may therefore have been largely due to the ice work. The principal trough (S. 38° W.) described by Sherzer and the first two sets of striæ (S. 31° W. and S. 68° W.) are evidently due to ice coming from the Lake Huron basin, and the last set (N. 29° W.) is due to ice flowing out of the Lake Erie basin.

The passage of the Erie ice over the Trenton reef could occur only when the Huron ice lobe ended some distance north of Trenton, probably at the Detroit interlobate moraine, which runs south from Birmingham through Detroit and thence southeastward nearly to the shore of Lake Erie at Leamington, Ontario, where it turns toward the east. Only for a relatively brief time would this peculiar relation of the two ice lobes exist, but it would occur both in the

[1] Sherzer, W. H., Geological report on Monroe County, Mich.: Michigan Geol. Survey, vol. 7, pt. 1, 1900, pp. 128-132, map opposite p. 112. The striæ near Trenton are discussed in Sherzer's paper on Ice work in southeastern Michigan: Jour. Geology, vol. 10, 1902, pp. 194-216; and more fully in his report on the geology of Wayne County: Rept. Michigan Geol. and Biol. Survey, 1911.

[2] In May, 1913, Mr. Leverett visited this quarry and found the order of development of the three sets of striæ to be as follows: (1) S. 31° W., (2) S. 68° W., and (3) N. 29° W.

A. GENERAL VIEW.



B. NEARER VIEW SHOWING PEBBLES IN RELIEF.

WAVE EROSION OF PRE-WISCONSIN TILL, RICHMONDVILLE, MICH.

A. OLD TILL WITH SOIL SOUTH OF AVOCA, MICH.

B. DISTANT VIEW OF THE ARKONA BEACH NEAR FARGO, MICH.

advancing and in the receding phase of the invasion. Moreover, it occurred, in all probability, twice in each of the great ice invasions that overspread the basins of Lakes Huron and Erie, for the observed disposition of the pre-Wisconsin drift, especially in the interlobate tracts in central and southeastern Michigan and in the western peninsula of Ontario, indicates the existence of Saginaw, Huron, and Erie ice lobes then in forms substantially identical with those of the last ice sheet. The troughs, lying with their axes in the line of ice movement at the last maximum, in all probability held the same relation to the maxima of each of the earlier invasions, and, in so far as they have been made by ice erosion, they may be in part a product of each of the invasions.

In Monroe County Sherzer reports three sets of striæ at Stony Point and Brest and two sets at each of the following places: Sissung Quarry, Point aux Peaux, Monroe, Maybee, Dundee, and Ottawa Lake. The latest striæ at Sibleys (N. 29° W.) are readily recognized in all these localities, and it is interesting to note that they incline more and more toward the west with increasing distance south from Sibleys, until at Ottawa Lake they run west or slightly south of west. This deflection is distinctly expressive of a lobe spreading northwestward, westward, and southwestward from a central point in the western basin of Lake Erie; and the striæ seem best interpreted as recording the spreading of one lobe at a particular stage and time.

The sets of striæ have another significance which is worthy of note. As Sherzer states, three sets at Sibleys are quite distinct from each other, the intermediate courses between each pair of contiguous sets being only sparsely represented. This seems to mean that a given set at this locality was made, not while the ice front was in active retreat, changing its alignment and shifting the courses of the lines of flow to the margin, but while the ice front was stationary or maintaining one position steadfastly. It is therefore concluded that each set of striæ stands for a pause in the retreat of the ice front, and hence corresponds to or is the correlative of a terminal moraine. From this point of view it seems probable that the striæ running N. 29° W. at Sibleys are correlatives of a moraine of the Lake Erie lobe which is itself the correlative or complement of the Birmingham moraine of the Lake Huron lobe and in part also of the Detroit interlobate moraine. Where no notable change of frontal alignment took place between the pauses in the retreat, the direction of the striæ might remain unchanged, and so represent more than one moraine. Such preservation of frontal alignment is generally maintained along the axis of a lobe; and the striæ running N. 29° W. at Sibleys, being nearly on the axis of the small sublobe which reached northwest from the mouth of Detroit River, may represent pauses of the ice front corresponding to all of the slender moraines from the Birmingham to the Mount Clemens.

CORRELATIVES IN OHIO, NEW YORK, AND ONTARIO.

By Frank B. Taylor.

GENERAL CORRELATION.

It seems certain that the group of slender moraines sweeps across the Maumee Valley from the Detroit interlobate moraine to the shores of the glacial lakes in eastern Ohio, Pennsylvania, and western New York. A number of the slender moraines are known to pass beneath the Maumee shores and they are believed to emerge east of Cleveland, where Mr. Leverett has mapped a number of moraines constituting his escarpment system.[1] Mr. Leverett shows others emerging farther eastward in Pennsylvania and New York.

The later moraines of the same series in Michigan sweep northeastward and northward through Ontario, emerging northwest of London. Thence they run northward and eastward around the upper edge of the highland south of Georgian Bay and, bending in wide curves, return southward on the east side, passing across the eastern end of Lake Erie. The writer has traced parts of all of those in Ontario,[2] and in all these localities the strength and character and general relations of these moraines show a strong resemblance to the system of slender individuals which is so well displayed in the eastern limb of the Saginaw lobe.

[1] Mon. U. S. Geol. Survey, vol. 41, pp. 651-672, Pls. XV and XVIII.
[2] The moraine systems of southwestern Ontario: Trans. Canadian Inst., vol. 10, 1913, pp. 1-23, with map.

DETROIT INTERLOBATE MORAINE IN SOUTHWESTERN ONTARIO.

On account of its intimate bearing upon the relations of the Huron and Erie ice lobes during the time of their shrinkage and separation the following facts are given relating to the moraines in the region east of Detroit River, chiefly in Essex, Kent, and Elgin counties, Ontario. The Detroit interlobate moraine runs southeast in a direct line from Detroit to the high ground a mile or two northwest of Leamington. It carries the Talbot road on its broad crest for a large part of the distance, and from Essex to 2 miles southeast of Cottam it carries also a finely formed gravelly bar of the Grassmere beach. From Leamington its probable continuation runs as a low, flat divide northeast to the county line and then east to Port Alma, where it forms a high bluff on the lake shore. To the east, after an interval of about 12 miles in which it has been cut away by the present lake, it reappears 5 miles southwest of Blenheim in a bluff 80 feet high as a more distinct morainic ridge, with beaches on its crest and flanks. From the lake shore it runs northeast through Blenheim and passes about 2 miles southeast of Ridgetown. A mile or two east of Port Alma small drainage courses, which formerly headed south of the bluff, show clearly the former existence of higher ground in that direction. From the trend of the ridge at both points on the bluff and from the decapitated stream beds it seems certain that part of this higher ground, now cut away by the waves, was at least 1 or 2 miles out from the present shore.

So far as can be judged on present information this ridge is continuous with the Detroit interlobate moraine and is interlobate in character throughout. It seems to have been begun at the time of the Birmingham moraine and probably represents several later subordinate halts of the ice front. If this ridge is interlobate it shows that at the time of its formation the Huron lobe was crowding the Erie lobe to the south and was even pressing slightly over into the space now occupied by Lake Erie. (See Pl. V, p. 62; also fig. 13, p. 485.) At earlier stages of the ice recession the interlobate line probably extended more directly southwest from Leamington; during the building of the Defiance moraine it probably terminated at the sand deposit in Fulton County, Ohio.

CHAPTER XI.

PORT HURON MORAINIC SYSTEM AND PROBABLE CORRELATIVES.

PORT HURON MORAINIC SYSTEM IN HURON AND SAGINAW BASINS.

By Frank B. Taylor.

GENERAL RELATIONS.

The Port Huron is a complex system of moraines rather than a single individual, but its component ridges are not so prominent as those of the West Branch-Gladwin group of moraines in the Saginaw Valley. The front ridge seems in most places like a strongly developed single moraine, and for this reason it has in the past been treated as a distinct individual and has been called the Port Huron moraine. It is of the substage order of magnitude and is, in fact, one of the best developed and most clearly defined moraines in the Great Lakes region.

After the Defiance moraine, which was traced from Ohio into Michigan as far as Adrian by G. K. Gilbert in 1870, the main moraine of the Port Huron system was the first to be distinctly recognized on the east side of the southern peninsula of Michigan.[1] Its relations to the Saginaw Bay and Lake Huron basins and to the intervening ridge of the "thumb" are so simple as to furnish an ideal illustration of the relation of the ice front to the larger elements of relief. On the "thumb," from Caro to Bad Axe and thence southward to Wadhams, it is a typical land-laid moraine, but in the central parts of the Saginaw and St. Clair valleys it is an equally perfect type of water-laid moraine, though when studied in detail it is found to be not a single ridge but a composite system.

The main moraine of the Port Huron morainic system played a more prominent part in the lake history, so far as that history has been worked out, than any other moraine in the Great Lakes region. The Huron-Erie glacial lakes had a more complicated history than those of any other basin, the principal cause of complexity being the oscillation of the ice front during the general retreat. Where the sequence of retreats and readvances was critically related to the retaining barrier of the lake waters, as it was on the "thumb" of Michigan, every movement of the ice front backward or forward affected the level of the waters. Oscillations of the ice front on the "thumb" of Michigan did not affect the level of the waters in the Saginaw basin, but nearly every movement changed the level of those in the Huron-Erie basin. In the early stages of these waters several changes of this kind occurred, and it has been difficult to unravel the complexities which they produced.

The main moraine of the Port Huron system marks a pronounced readvance of the ice front and records one of the simplest of these changes, uncomplicated by any later or earlier ones. The ice formed the barrier which retained Lake Whittlesey, and its readvance raised the waters of the lake more than 40 feet, submerging the earlier Arkona beaches. It was in connection with this moraine that the effects of readvance in raising lake waters were first recognized.

Besides its critical relation to the Huron-Erie lakes, this main moraine is distinguished above the others by having been traced continuously across the Great Lakes region for a greater distance than any other. Mr. Leverett describes its distribution and characteristics at points farther north and west (see pp. 302–315) and the writer has traced it eastward across Ontario into New York.

Two other fainter water-laid moraines belonging to the Port Huron system lie between the main moraines of the system and the shore. The first, the Bay City moraine, surrounds Saginaw Bay from Iosco County to northern Huron County. The other, the Tawas moraine, is a fragment which lies near the shore in Iosco and Arenac counties.

[1] Correlation of Erie-Huron beaches with outlets and moraines in southeastern Michigan: Bull. Geol. Soc. America, vol. 8, 1897, pp. 41–43.

MAIN MORAINE OF PORT HURON MORAINIC SYSTEM.

DISTRIBUTION.

In northwestern Iosco County Au Sable River cuts a trench over 200 feet deep in the drift deposits and at this point the main moraine of the Port Huron system is interrupted by a break 6 or 7 miles wide.

South of Au Sable River the moraine is spread out upon a till plain with three or four weaker ridges openly deployed. It also embraces a ridge of considerable strength along the east section of Rifle River in eastern Ogemaw County. These ridges converge toward the great bend of Rifle River in the northern part of Arenac County. The front or earliest ridge is much stronger than the others. From the Au Sable it runs westward to 7 or 8 miles east of Rose City, where it turns abruptly and runs directly south to a point about 4 miles west of Prescott.

East of this and apparently next in order of formation is a weaker, irregular morainic deposit which runs west for 5 miles into Ogemaw County and then turns south for 10 miles, ending in a till plain without clear connection with the other ridges.

Another slender ridge runs directly southwest for about 25 miles to the bank of Rifle River, 2 miles west of Melita, in Clayton Township.

From the southwest corner of Iosco County a strongly developed ridge, known locally as Maple Ridge, runs more westerly to a point 3 or 4 miles east of Melita, and also eastward 5 or 6 miles to the Au Gres River. On the same line produced, on the west side of Rifle River, a morainic ridge of moderate strength runs southwest nearly to the Arenac County line, where it turns south and runs in fainter, broken form to the northwest corner of Gibson Township, the northernmost township of Bay County. Another lighter till ridge starts from the bank of Rifle River at the bend about 3 miles north of Sterling and runs southwest to Pine River about 3 miles west of Sterling. Then after a break of 2 or 3 miles this ridge reappears and curves southward and joins the other ridge from the north in northwest Gibson Township. Outside of these ridges in the northwest part of Arenac County and neighboring parts of Ogemaw and Gladwin counties is a moraine which seems to fall in the Port Huron morainic system but which dies out in a sandy plain east of Tittabawassee River and is not recognized farther south.

In eastern Gladwin County the main moraine appears to become water-laid and it begins also to be largely covered with fine sand, which was blown over it, in part at least, from the wide sandy plain which borders it on the west, and perhaps in part also from beaches lying near its crest. Where it is water-laid, the moraine loses its relief with reference to the country around it. It runs southward through eastern Gladwin County as a broad, low ridge that controls the drainage but grows constantly less conspicuous. After entering northeastern Midland County it turns gradually southeast and follows the east bank of Tittabawassee River to Saginaw, where it ceases to be perceptible to the eye. It continues, nevertheless, in the same line along the north side of Cass River and governs the course of that stream to the vicinity of Vassar, near which it again emerges from the lake bed. North of Vassar it becomes prominent and extends directly northeast along the north bank of Cass River to the hilly interlobate region southeast of Bad Axe in southern Huron County.

In its water-laid part in the Saginaw Valley the moraine seems to be single. Five or six miles north of Caro, however, it begins to show more than one line of knolls and becomes distinctly composite. The front line keeps the more direct course and passes northeastward a little north of Cass City, north and northeast of which it is broken. The most prominent ridge back of this turns north through eastern Elmwood Township, Tuscola County, and runs past Gagetown, from which place it runs northeastward to the vicinity of Bad Axe in Huron County; but from a point 3 or 4 miles northeast of Gagetown it is much weaker. Between these two ridges, along Cass River in northeastern Tuscola and southern Huron counties, scattered detached knolls and short ridges lie in a till plain, but no clearly developed moraine is visible.

The higher irregular ground of the interlobate tract lies principally in southeast Verona Township, Huron County, but partly also in northeast Bingham, western Sigel, and northwestern Paris townships.

In sec. 2, Bingham Township, the front ridge of the Saginaw lobe met the front ridge of the Lake Huron lobe at an angle slightly less than a right angle and just here there is a narrow depression through which Willow River flows northward.

From this point the front ridge of the Lake Huron lobe runs southeast into the north edge of Sanilac County, where it turns more southward to the north bank of Black River opposite Wadhams, 7 miles west of Port Huron. From Huron County to this point the moraine ridge is very strong, but at Black River it passes under the level of the Warren beach and thence southward it is a low, broad water-laid ridge mainly covered with sand. It crosses St. Clair River into Canada a mile north of St. Clair.

TOPOGRAPHY.

ALTITUDE AND RELIEF.

The western or front ridge in Ogemaw and Iosco counties is fairly strong. From an altitude of 930 to 950 feet in northeastern Ogemaw and northwestern Iosco counties it falls to 850 to 875 feet at the north edge of Arenac County. Its front relief is generally 50 to 60 feet and its inner relief 25 to 30 feet.

The other branching ridges in eastern Ogemaw and western Iosco counties are rather ill-defined as ridges and have low relief. The knolls are generally not over 10 to 15 feet high. Their altitude ranges from 920 or 930 feet in northwestern to slightly below 800 feet in southwestern Iosco County. Maple Ridge has an altitude of about 850 feet near the village of Maple Ridge and of about 860 feet a mile north of Melita. West of Rifle River its continuation has an altitude of from 820 to 840 feet and a relief of 40 to 50 feet. The narrow ridge northwest of Sterling has an altitude of 780 to 800 feet and its continuation into Gibson Township, Bay County, has an altitude of 825 feet, declining southward to about 810 feet before it begins to be covered with sand and gravel. The relief of these ridges is generally 20 to 30 feet.

In its water-laid part the moraine descends from about 800 feet in western Gibson Township to 700 feet about 10 miles north of Midland and to 600 feet at Saginaw. From Saginaw it rises again to 700 feet at Vassar, where it again becomes land laid. From Vassar to Bad Axe and thence south to Black River near Port Huron the Warren beach is the highest shore line on the inner or lakeward slope of the moraine, but from Vassar to Cass City the outer slope of the moraine was washed by the waters of Lake Saginaw at the level of the Arkona beaches, which are 20 to 40 feet higher. The limits of the lake waters on the two sides of the moraine in northwestern Bay County were not definitely determined, partly because the moraine shows much less change of expression in passing from land-laid to water-laid form, but mainly because the whole area is covered and obscured by sand.

Between Vassar and Gagetown the moraine has a number of knolls which rise above 800 feet and a relief of about 100 feet on both sides. The ridge has an unusually sharp and narrow crest between Watrousville and Ellington. North of Cass City the front ridge is much broken and its scattered knolls are below 800 feet.

From this point a narrow crest rising above 800 feet and in some parts to 865 feet runs continuously to the interlobate angle. The ridge which extends to Gagetown reaches above 800 feet at a number of points south of that place, but is a little lower farther north. The highest point on the moraine is on a knob just west of the cleft in the interlobate angle where the topmost point is a little above 890 feet.

The relief of the moraine northeastward from Cass City is generally nearly 100 feet on the outer slope and about 50 feet on the inner slope. In the interlobate area north of the angle the relief is generally 70 to 80 feet and the altitude 810 to 820 feet, with some points reaching 860 feet.

From the interlobate angle southeastward into Sanilac County the altitude of the moraine is 850 to 860 feet and the relief on both sides 50 or 60 feet. Southward the altitude declines very gradually to about 800 feet at Carsonville, 760 or 770 feet at Amadore, and 730 or 740

MAIN MORAINE OF PORT HURON MORAINIC SYSTEM.

DISTRIBUTION.

In northwestern Iosco County Au Sable River cuts a trench over 200 feet deep in the drift deposits and at this point the main moraine of the Port Huron system is interrupted by a break 6 or 7 miles wide.

South of Au Sable River the moraine is spread out upon a till plain with three or four weaker ridges openly deployed. It also embraces a ridge of considerable strength along the east section of Rifle River in eastern Ogemaw County. These ridges converge toward the great bend of Rifle River in the northern part of Arenac County. The front or earliest ridge is much stronger than the others. From the Au Sable it runs westward to 7 or 8 miles east of Rose City, where it turns abruptly and runs directly south to a point about 4 miles west of Prescott.

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ALTITUDE AND RELIEF.

The western or front ridge in Ogemaw and Iosco counties is fairly strong. From an altitude of 930 to 950 feet in northeastern Ogemaw and northwestern Iosco counties it falls to 850 to 875 feet at the north edge of Arenac County. Its front relief is generally 50 to 60 feet and its inner relief 25 to 30 feet.

The other branching ridges in eastern Ogemaw and western Iosco counties are rather ill-defined as ridges and have low relief. The knolls are generally not over 10 to 15 feet high. Their altitude ranges from 920 or 930 feet in northwestern to slightly below 800 feet in southwestern Iosco County. Maple Ridge has an altitude of about 850 feet near the village of Maple Ridge and of about 860 feet a mile north of Melita. West of Rifle River its continuation has an altitude of from 820 to 840 feet and a relief of 40 to 50 feet. The narrow ridge northwest of Sterling has an altitude of 780 to 800 feet and its continuation into Gibson Township, Bay County, has an altitude of 825 feet, declining southward to about 810 feet before it begins to be covered with sand and gravel. The relief of these ridges is generally 20 to 30 feet.

In its water-laid part the moraine descends from about 800 feet in western Gibson Township to 700 feet about 10 miles north of Midland and to 600 feet at Saginaw. From Saginaw it rises again to 700 feet at Vassar, where it again becomes land laid. From Vassar to Bad Axe and thence south to Black River near Port Huron the Warren beach is the highest shore line on the inner or lakeward slope of the moraine, but from Vassar to Cass City the outer slope of the moraine was washed by the waters of Lake Saginaw at the level of the Arkona beaches, which are 20 to 40 feet higher. The limits of the lake waters on the two sides of the moraine in northwestern Bay County were not definitely determined, partly because the moraine shows much less change of expression in passing from land-laid to water-laid form, but mainly because the whole area is covered and obscured by sand.

Between Vassar and Gagetown the moraine has a number of knolls which rise above 800 feet and a relief of about 100 feet on both sides. The ridge has an unusually sharp and narrow crest between Watrousville and Ellington. North of Cass City the front ridge is much broken and its scattered knolls are below 800 feet.

From this point a narrow crest rising above 800 feet and in some parts to 865 feet runs continuously to the interlobate angle. The ridge which extends to Gagetown reaches above 800 feet at a number of points south of that place, but is a little lower farther north. The highest point on the moraine is on a knob just west of the cleft in the interlobate angle where the topmost point is a little above 890 feet.

The relief of the moraine northeastward from Cass City is generally nearly 100 feet on the outer slope and about 50 feet on the inner slope. In the interlobate area north of the angle the relief is generally 70 to 80 feet and the altitude 810 to 820 feet, with some points reaching 860 feet.

From the interlobate angle southeastward into Sanilac County the altitude of the moraine is 850 to 860 feet and the relief on both sides 50 or 60 feet. Southward the altitude declines very gradually to about 800 feet at Carsonville, 760 or 770 feet at Amadore, and 730 or 740

feet a mile or two north of Black River. The relief on the outer border continues about the same, except that Black River cuts deeper as it flows south.

From Wadhams to St. Clair the water-laid moraine declines from about 680 to about 625 feet; its relief on the outer slope is only 5 or 10 feet near Black River and 20 or 25 feet near St. Clair; on the inner slope its relief is slightly greater.

CHARACTER.

The front ridge of the main moraine of the Port Huron system in Ogemaw and Iosco counties is strong and has mainly swell and sag topography with scattered basins. The fainter branches east of the front ridge have comparatively low knolls and are not conspicuous as ridges; among them basins are numerous and more prominent than knolls.

Maple Ridge, in southern Iosco and northern Arenac counties, is a strong moraine with mostly swell and sag topography. It runs southwest as a high and prominent feature and terminates abruptly at the edge of the 200-foot deep ravine of Rifle River. From its end a commanding view is obtained over the lower sandy plain to the north and west.

Southwest from Rifle River Maple Ridge is not so strongly and evenly developed, but has a swell and sag topography. Where it turns south near the county line it becomes broken and discontinuous. The fainter ridge which runs southwest west of Sterling has mainly a swell and sag topography. On entering Bay County the main ridge at first has a moderately undulating topography, but as it begins to be water-laid it becomes smooth and broad and without conspicuous surface features. Toward Saginaw it becomes so broad and flat that it ceases to be a visible ridge; shortly, however, it resumes the form of a broad, smooth ridge, and a little north of Vassar it becomes a rugged land-laid moraine with a mainly swell and sag topography of rather pronounced type, carrying some basins and a number of high, rather sharp knolls. Toward Gagetown the inner ridge is broken and irregular with mainly a swell and sag topography. Near Cass City the front ridge is still more broken, and much of the area between Cass City and Gagetown is a flat till plain bearing only scattered low knolls.

In Huron County west of the interlobate angle the front ridge is of the swell and sag type; and the area between this and the Gagetown ridge, which is much weaker, is largely a plain with only scattered low knolls.

The interlobate area east of Bad Axe is mainly composed of rather high knolls and swampy troughs. There are many small basins, but the knolls are much more prominent.

Nearly all of the moraine from the interlobate angle to Black River, 7 miles west of Port Huron, has a moderate swell and sag topography with comparatively few basins. This part of the moraine, however, is composed of three or four parallel subordinate ridges whose crests are generally quite clearly defined and have long longitudinal sags between them. Thus, though the bulky ridge is compound, its separate elements are related in the simplest possible way. There are very few basins in this part. The surface forms are excellent types of swell and sag topography.

South of Wadhams, on Black River, the water-laid continuation of the moraine is a broad, low ridge largely covered with sand.

STRUCTURE OF THE DRIFT.

THICKNESS.

In eastern Ogemaw and western Iosco counties the drift has a thickness of 100 to 200 feet. Near Tawas and southwestward to northern Bay County the drift within 5 or 10 miles of the shore is thin, varying from nothing to 50 or 75 feet. In western Arenac the thickness is about 200 feet, and along the course of the main ridge in Gladwin, Midland, and Saginaw counties it is generally 200 feet. From Saginaw eastward, however, its depth is about 100 feet to the north edge of Tuscola County, except along the high crest of the moraine northeast of Vassar, where it is nearly 200 feet. In Huron County outside of the interlobate area the drift is in few places more than 50 feet thick and at many places near the shore is very thin or absent. Near

the shore in Bay County the thickness is about 100 feet. In Sanilac County the thickness along the moraine to the vicinity of Carsonville is about 150 feet and along the shore 20 to 50 feet. From the vicinity of Port Sanilac to Port Huron and St. Clair the thickness is 200 feet or more.

COMPOSITION.

In Iosco and eastern Ogemaw counties the main moraine of the Port Huron system is bowldery and contains notable amounts of gravel and sand. The land-laid parts on the "thumb" are also bowldery. But aside from these bowldery parts and the surficial sands and gravels of the beaches, the drift of this whole district is notable for the large predominance of clay in its composition.

At Tawas, Lexington, and other places near the lake shore, there are flowing wells which seem to issue from porous beds beneath the till sheet of the moraine. The beds are inclined upward inland and have their intake areas at higher levels some miles back from the shore, and the water percolates down the slope under the inclined surficial till sheet.

TILL PLAINS.

In eastern Ogemaw and western Iosco counties the area east of the front ridge of the main moraine of the Port Huron system is a till plain of considerable extent. It carries only low, undulating ridges but is characterized by a great many basins, many of them deep and a considerable number containing lakes. The lands surrounding the area carry mainly sand and gravel of low fertility, but the area itself has a fertile clay soil that promises excellent results under cultivation.

A small till plain above the level of the lake waters lies along the south side of the older moraine fragment in northwestern Arenac County. Small till plains are included between the outer and inner ridges of the moraine between Cass City and Gagetown and southwest of Bad Axe. A narrow till plain lies between the Warren beach and the inner slope of the moraine in southeastern Huron County and extends for about 10 miles southward into Sanilac County.

The lake bottom below the level of the highest beach commonly has more or less of the character of a till plain, but wave work along the lines of the several beaches has modified the surface considerably both by erosion and deposition. Considerable parts of the drift have been removed, leaving bowlders on the eroded surface, and sands and gravels have been deposited in extensive beach ridges and sand belts. The finer sediments were carried away and deposited in deep water. Where the basins were deepest, immediately in front of the ice, lake clays of considerable depth were deposited. A large area in the low part of the Saginaw Valley outside of the main moraine of the Port Huron system contains 50 to 100 feet of lake clay without stones or sand. A thickness of 90 feet was penetrated at St. Charles in a coal shaft; and 150 feet or more is reported to lie in the Lake St. Clair basin south of the moraine.[1]

OUTWASH.

While the ice front was resting on the front ridge of the Port Huron system in Ogemaw and Iosco counties, a large river followed the course of the Au Sable to the bend in northwestern Iosco County and thence went west and south along the front of the moraine into southern Ogemaw and northern Gladwin counties.

The descent of this stream was rapid, and although it probably obtained a considerable amount of sandy outwash directly from the ice front, it must also have gathered much from the erosion of its bed, for almost its whole course was through older sandy outwash deposits. It carried enormous quantities of sand into southern Ogemaw and northern Gladwin counties and spread them in a relatively thin sheet over the flat areas of that region, covering up what would otherwise doubtless have remained a fertile till plain suitable for cultivation, and covering also in all probability the Arkona beaches northward from a point 7 miles northeast of Gladwin

[1] Cole, L. J., Delta of the St. Clair River: Michigan Geol. Survey, vol. 9, pt. 1, 1903, p. 14.

and thus making it impossible to learn anything definite about the relation of these beaches to the main moraine in this locality.

More or less outwash issued directly from the ice along its front, but no notable deposit is known with certainty, except in Sanilac County, where a thin, narrow sheet of sandy outwash spreads like an apron from the front of the moraine from Amadore northward nearly to the Huron County line. Although this deposit is relatively small and narrow, its southern part buried two of the beaches of Lake Arkona.

The total absence of outwash along some parts of the moraine front is more remarkable than its presence in other places. From a mile west of Amadore southward to the junction of Mill Creek with Black River, no outwash whatever is visible, and the condition of fragments of the lower Arkona beach, which lie in actual contact with the base of the front slope of the moraine, proves conclusively that none was ever deposited.

GLACIAL DRAINAGE.

UBLY CHANNEL.

While the ice front was resting on the main moraine of the Port Huron system the Huron-Erie basin was occupied by Lake Whittlesey. The lake discharged through a long, narrow bay, called Black River Bay, which extended from a 3-mile entrance between Spring Hill and Zion, 14 miles northwest of Port Huron, northward for 50 miles, nearly to Ubly. From a swamp at the head of this bay the outlet ran close along the ice front in the reentrant angle on the "thumb," and the channel now marking its course lies close along the front of the moraine from 3 miles east of Ubly to Cass City, about 18 miles on the course of the channel, where it enters Lake Saginaw.

The Ubly channel is short, but it is one of the large, important channels of the Great Lakes region. Its head is 3 miles east of Ubly, in a swamp whose waters flow northwest to the North Branch of Cass River. Two miles southeast of the divide at the head of the channel the swamp is less than a mile wide, but on the divide its width is about 2 miles and it continues with this width to the bend of Cass River in sec. 15, Bingham Township. Here the channel turns sharply southwest through a passage not over three-fourths of a mile wide and continues thence past Ubly to Cass City with a width of 1 to 1½ miles.

A high till ridge just east of Ubly separates it from the head of the channel at the divide. On the west side of this ridge another narrower passage, floored with sandstone in nearly horizontal beds, runs northwest from the Black River swamp a mile or two southeast of Tyre and once carried a large body of water to the main channel at Ubly. Tyre stands on the floor of this branch channel.

The floor of the Ubly channel shows more pronounced evidences of scour by a large river than do most of the glacial channels. Comparatively little of it is swampy, this character being confined mainly to its upper and lower reaches. The rest of it is floored with immense numbers of bowlders and at places with pebbly or gravelly bars, some of them 8 or 10 feet high, whose shapes show distinctly that they were produced by a strong current flowing southwest.

At Holbrook, in northeast Greenleaf Township, a passage opens into another channel lying close south of the Ubly.

Cass City is built on a gravelly terrace which appears to be partly the product of a glacial stream coming from the northwest through the moraine and partly a delta deposit of the Ubly outlet river.

The present altitude of the floor of the channel is about 800 feet at its head and about 740 feet a mile or two east of Cass City. The channel lies nearly in the direction of maximum uplift, about N. 22° E., and runs almost directly down the slope of the tilted land. From its present fall of nearly 60 feet it is necessary therefore to subtract 15 or 16 feet in order to find its original descent of 40 to 45 feet. This original descent is the difference in the altitudes of Lakes Whittlesey and Saginaw and indicates the amount that the Huron-Erie waters were raised by the readvance of the ice front to the front ridge of the Port Huron morainic system.

CUMBER, HAY CREEK, ARGYLE, AND BAD AXE SPILLWAYS.

The Cumber, Hay Creek, Argyle, and Bad Axe spillways appear to have been uncovered in successive order from south to north during the retreat of the ice front, and all of them are probably somewhat older than the Ubly channel, for they were made when the ice was beginning its retreat to a position farther north than that marked by the Port Huron system. The Ubly channel was made only when the ice front had readvanced to the position of the main Port Huron moraine. The retreat and readvance of the ice front at this time will be more fully discussed later. (See pp. 362–385.)

Cumber spillway.—The Cumber spillway, which lies close south of the Ubly outlet, is in its lower three-fourths almost as well developed as the Ubly. In its headward part it is not maturely developed. It opens westward out of Black River swamp south of Tyre through two or three head branches whose floors are of stony till and were not much deepened although considerably widened by the flow of the lake waters. The Cumber spillway is particularly well developed in western Austin and southwestern Greenleaf townships, where the stony till ridge between the Ubly channel on the north and the Cumber on the south is hardly half a mile wide and seems clearly a remnant left from the scouring of the two channels. Rock ledges are exposed in it just east of Holbrook. The lower part of this channel in southwestern Greenleaf is as finely developed as the Ubly channel; in it is located the "stone wall"[1]—a small rampart ridge of bowlders produced apparently by the onshore shoving of ice in a shallow bay or lake—described by Gordon and others.

The Cumber channel extends southwestward to the middle of Novesta Township, Tuscola County, and may connect with the bowldery belt in Novesta and Wells townships and farther on with the East Dayton channel. This correlation, however, seems very doubtful in view of the differential uplift of the land. The flat ground upon which it emerges has now an altitude between 740 and 745 feet, which is about the same as that of the head of the East Dayton channel. Before the elevation of the land the ground in Novesta Township was about 15 feet lower, which would leave little or no declivity toward the southwest and little chance for scour along the line of the bowlder belt.

Hay Creek spillway.—Opening from the swamp east of Frieburger another smaller spillway runs west to a point south of Cumber and thence southwest down Hay Creek to the middle branch of Cass River. The lower part of the Hay Creek spillway was deeply cut and has a swampy floor, but it is relatively narrow and its headward parts are undeveloped.

Argyle spillways.—In Argyle Township two headward branches of Cass River join and flow westward. Although they have no well-developed channel they flow in valleys which seem much too large for them and which evidently served as temporary spillways.

The south branch of Cass River follows a line of swamps which may be in part an esker trough, but which may have been a temporary spillway joining the Argyle spillway at Shabona. The swamp forks in the southeast part of Lamotte Township, one branch going northwest past Novesta; neither branch shows distinct scour, but both may have served as very temporary spillways.

Bad Axe spillways.—When the ice front began to recede from the Port Huron morainic system it uncovered ground slightly lower than the col at the head of the Ubly channel and permitted the formation of two winding, swampy passages that led through the interlobate hills between the Ubly channel on the south and the edge of the interlobate high ground at Bad Axe and Verona Mills on the north. These channels are only 70 to 80 rods wide, but their bowldery, swampy floors show the scour of the stream that passed through them. One of them is about 4 miles north of Ubly and passes close to Wadsworth with an altitude of 785 to 790 feet. The other somewhat wider channel lies about a mile south of Verona Mills. It seems evident that these channels were occupied for a relatively short time and that they probably divided the overflow with the Ubly channel.

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[1] Gordon, C. H., Geological report on Sanilac County: Michigan Geol. Survey, vol. 7, pt. 3, 1900, pp. 18-20. Taylor, F. B., Bull. Geol. Soc. America, vol. 8, 1897, pp. 43-44.

The most important of these transitory channels is a still later one which runs along the base of the hills north of Verona Mills and, turning in a direction a little south of west, passes just north of Bad Axe. This channel is a mile wide and is a well-marked scoured depression with a bowldery floor. It was formed when the ice front rested on the ridge which runs along its north side. This channel probably carried the whole discharge, leaving the Ubly channel dry. At this time a long, narrow, shallow lake, running southeast from near Verona Mills into Sanilac County, covered the flat ground between the ice front and the recently abandoned moraine. This lake was not a part of Lake Whittlesey, but was an independent though very short-lived body. During this same time two or three similar shallow lakes lay on the west side between Bad Axe and Gagetown. The waters of all these channels and lakes finally reached Lake Saginaw through the transverse channel from Gagetown to Cass City.

At the last stage, however, the water appears to have taken a different course at the southwest, for between Popple, Rescue, and Gagetown, and extending several miles farther southwest, the inner slope of the latest ridge of the Port Huron morainic system is heavily cut at or a little above the level of the Warren beach, making a steep bluff which extends for many miles and seems much too great to be attributed solely to the waves of Lake Warren, especially when it is noted that scarcely any other part of the Warren shore presents a wave-cut bluff. It seems certain that during the last stand of the ice along this ridge the water, coming probably from the Bad Axe spillways, found a temporary constricted passage between the ice and the morainic ridge, and it was mainly the cutting of that stream that made the bluff. The gravels gathered from this cutting were carried southwestward toward Vassar. Later the waves of Lake Warren, working at nearly the same level, did some further cutting at the base of the bluff, but this effect was probably not great, for at some places the waves did not reach the bluff. At the same time, besides contributing considerable fresh gravel to the deposits near Vassar, the waves worked over those previously deposited by the temporary river. The cutting of the inner slope in this stretch is much like that which affected the Birmingham moraine at Romeo. (See p. 284.)

BAY CITY MORAINE.

Inside of the main moraine of the Port Huron system of the Saginaw basin and 10 to 12 miles nearer the lake runs another much fainter morainic belt known as the Bay City moraine. Its faintness suggests that it is a subsidiary ridge of the Port Huron system, but it is all deeply water-laid and its faintness alone is not a safe criterion. In its distribution it appears to be independent, though it seems hardly likely that it marks a substage.

A moraine which is doubtfully correlated with the Bay City moraine begins 5 or 6 miles northwest of Tawas on a rugged slope of bowlder clay which forms a sort of retaining wall for the south part of the great delta of Au Sable River. The moraine runs slantingly down the slope from about 750 feet altitude to about 650 feet. From its top the edge of the delta extends away north and northwest as a sand plain. The moraine is gullied by ravines that run down the slope, but it seems to have had a swell and sag topography considerably modified by erosion.

To the southwest for 5 or 6 miles this fragment gives place to a sandy country, but it may be continued by a low stony till ridge which sets in close east of Turner and Twining in Arenac County. This ridge trends southwest in direct line with other faint knolls, near Omer and Standish, which clearly belong to the Bay City moraine.

From this place the moraine continues southwest into Bay County, bending gradually around to the south and southeast and keeping 5 to 8 miles from the shore, and crosses Saginaw River at Bay City as a distinct though faint ridge. From Bay City it bends southeast 7 or 8 miles, passing around the south side of the swamps of Quannicassee. Then from the southeast corner of Bay County it runs northeast through Tuscola County, keeping 5 to 6 miles from the shore and passing Fairgrove and Unionville. In southwestern Huron County it is weaker, but it reappears in fair strength 4 miles north of Elkton, beyond which it is represented by an ill-defined bench and a bowldery belt, which runs northeast through Meade Township into eastern Dwight Township and then swings southeast through Huron Township. A shore line

connected with the bowldery belt is much more bowldery where it lies on the morainic bench than it is elsewhere.

The Bay City moraine is water-laid throughout. Its altitude is 750 to 650 feet west of Tawas and about 640 feet at Turner and Twining in Arenac County. It declines very gradually southward to 605 or 610 feet at Bay City. Its relief is very low, generally under 10 feet. Northeastward from Bay City its altitude rises gradually to about 655 feet 3 miles north of Elkton.

TAWAS MORAINE.

A narrow faint ridge of stony till, beginning at the lower edge of the sandy deposits south of Au Sable River, runs a little west of south through Wilber Township, passing west of Tawas Lake, to the western edge of the village of Tawas in Iosco County. This ridge, known as the Tawas moraine and regarded as a member of the Port Huron morainic system, runs southward in fair strength to Alabaster and thence in fading form into northeast Arenac County. About 5 miles west of Tawas a few very low knolls with some stones trend northeast and southwest and seem to mark a faint earlier moraine.

The altitude of the Tawas moraine in Wilber Township is 625 to 630 feet, and it declines southward to 600 feet or less in eastern Arenac County. Two or three miles north of Alabaster it rises to 640 feet. Its relief near its north end is 15 to 20 feet, but declines southward to 5 or 10 feet. Where it is partly cut away along the shore between Tawas and Alabaster its relief is 15 to 20 feet on the outer slope.

About a mile south of Port Austin and near the shore in northern Huron Township three or four prominent knolls suggest by their altitude and location a correlation with the Tawas moraine.

CORRELATIVES OF THE PORT HURON MORAINIC SYSTEM IN ONTARIO AND NEW YORK.

By Frank B. Taylor.

Since 1893 the writer has made occasional studies of the Pleistocene formations in Ontario, chiefly on the southwestern peninsula. Although the results are still somewhat fragmentary they are fairly complete in some areas and show the general plan of the terminal moraines of the region.[1]

The Port Huron morainic system on the east side of Lake Huron has the same habit of expression that it has on the "thumb" and in the Saginaw Valley in Michigan. In a few places it is composite, but generally it forms a single strong ridge. It has been traced continuously from Mooretown on St. Clair River, where it is water-laid and faint in its expression, past Wyoming, eastward north of Arkona, northward west of Ailsa Craig to the bend of Maitland River, and northeastward along the north side of this river to a point 5 or 6 miles north of Wingham. Beyond this it has been identified at several places as far as Markdale and beyond that has been mapped in detail to the escarpment west of Collingwood.

In the basin of Lake Ontario the identification of this moraine has been made out satisfactorily in western New York and across the Niagara peninsula to the vicinity of Hamilton, and it is known with approximate accuracy northward along the escarpment to a high angle on the great promontory west of Collingwood. The identity of the moraine was made sure by its relation to the Whittlesey, Arkona, and Warren beaches at Marilla and Alden, 20 miles east of Buffalo.

In the Ontario basin and the east end of the Erie basin this morainic system has a different expression from that which it shows in the Lake Huron basin. Its component ridges spread apart on the plain after the manner of the slender ridges of the West Branch-Gladwin group of moraines in the Saginaw Valley. It would seem probable, therefore, that three or four or perhaps more of the slender moraines in western New York and on the Niagara peninsula in Ontario form a group which is as a whole the equivalent of the massive moraine of the Port

[1] The moraine systems of southwestern Ontario: Trans. Canadian Inst., vol. 10, 1913.

Huron morainic system on the "thumb" of Michigan. When the ice front was resting on this moraine on the "thumb" it made at least three or four subordinate oscillations before it uncovered lower ground and allowed the waters of Lake Whittlesey to fall to lower levels. At the east end of Lake Erie these three or four ridges were not set close together but were deployed at considerable intervals, and during the making of the first three or four the level of Lake Whittlesey was not affected. Apparently the Alden moraine was the last ridge made while Lake Whittlesey kept its level. This moraine is therefore believed to be the correlative of the last of the secondary ridges on the "thumb" which held Lake Whittlesey up to its level. The eastern equivalents of the Port Huron morainic system include in all probability the Gowanda, Hamburg, Marilla, and Alden moraines as described by Mr. Leverett.[1]

PORT HURON MORAINIC SYSTEM IN NORTHERN HURON AND NORTHERN MICHIGAN BASINS.

By Frank Leverett.

GENERAL RELATIONS.

In the northern part of the southern peninsula a complex group of moraines appears to continue the Port Huron morainic system to the north and west from the Au Sable Valley, where Mr. Taylor's description ends. (See pp. 293–301.) It embraces all the moraines and associated glacial features found on the slopes descending toward the northern end of Lakes Huron and Michigan from the great table-land in the northern part of the southern peninsula. The moraines of this system in places show a discordance in relation to the earlier ones such as might result from a readvance following a marked recession of the ice border. Further evidence that the moraines of this group are markedly younger than the ones outside is shown by the relation of the moraines in the Michigan basin to the beaches of Lake Chicago. It is by means of this relation to the beaches that correlations have been made with moraines on the Wisconsin side of Lake Michigan.

DISTRIBUTION.

In the northern part of the southern peninsula the border of this morainic system follows the northern edge of the high table-land in which Au Sable and Manistee rivers rise. It is accompanied by a great outwash gravel plain or apron that bears evidence of a prolonged stand of the ice border at this culminating position. From the Au Sable Valley in eastern Oscoda County the outer moraine leads northwestward across Montmorency to northwest Otsego County, where there was a reentrant between the Huron and Michigan lobes. Thence it goes southwestward through Antrim and Kalkaska counties, keeping just east of the line of the Grand Rapids & Indiana Railway, leads westward across southern Traverse County, and turns south through eastern Manistee County, keeping a few miles back from Manistee River throughout its course in these counties to the latitude of Manistee, where it crosses the river, beyond which it is continued only as disjointed ridges. These ridges lead southwestward nearly to the shore of Lake Michigan in western Mason County at the east end of Hamlin Lake, then make a southeastward detour into southern Mason County and come back to the shore of Lake Michigan south of Ludington. In Oceana County they are in places banked against the western end of the great spur of the Lake Border system (p. 223). South of this spur are two ridges. One, known as the Whitehall ridge, lies 3 to 5 miles back from the shore of the lake and is traceable past Whitehall to Muskegon, south of which it passes into Lake Michigan. West of Whitehall in northern Muskegon County a second ridge, which seems closely related to the outer one, appears for a few miles along the shore of Lake Michigan; it was not recognized farther south than White Lake.

On the Wisconsin side of Lake Michigan the correlative of this moraine seems to be found in a deposit of red till which covers a narrow strip on the coast from Milwaukee north-

[1] Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 673–685. See also Niagara folio (No. 190), Geol. Atlas U. S., U. S. Geol. Survey, 1913, fig. 8, p. 17; also Trans. Canadian Inst., vol. 10, 1913, map opposite p. 23.

ward to the base of the Green Bay peninsula, where it curves back to the southwest and north into the Lake Winnebago basin, passing to the south end of that lake. Its course has not been fully determined from Lake Winnebago northward, but it probably correlates with a moraine which crosses the State line of Wisconsin and Michigan east of Florence, Wis., and runs northward along the east side of Michigamme River about to the latitude of Channing, where it turns westward at a reentrant between the Green Bay lobe and the more western portion of the ice field. Studies in 1910 in the Northern Peninsula of Michigan, northern Wisconsin, and northeastern Minnesota seem to give warrant for correlating this morainic system with one which sweeps around the head of Lake Superior, but the facts can be fully established only by further field work.

Present knowledge at least suggests that the glacial readvance marked by the Port Huron morainic system continued all the way from New York to Minnesota or entirely across the Great Lakes basins. A similar readvance is indicated in the ice field which covered the Red River basin west of the Great Lakes, a basin which subsequently held Lake Agassiz.

TOPOGRAPHY.

CHARACTER.

Considerable variation is displayed by this morainic system in its circuit of the northern Huron and northern Michigan basins. On the slope toward the Huron basin lie great morainic spurs extending toward the lake from the outer ridge of the system and isolated island-like tracts of moraine surrounded either by sand or till plains. (See Pl. VII.) In Oscoda County, and to some extent in Otsego County, plains separate the spurs or transverse ridges from the outer ridge of the system, but in the intervening district in Montmorency County the spurs are very closely connected with the outer moraine. Toward Lake Huron from this outer moraine the ridges become less closely aggregated and much of the surface is occupied by till and sand plains.

In the reentrant angle between the Huron and Michigan lobes in northern Otsego and eastern Charlevoix counties morainic topography is prominently developed as far north as the lowland which leads from Little Traverse Bay eastward to Burt Lake, and very prominent morainic tracts extend north of this lowland, one of them reaching the shore of Lake Michigan north of Little Traverse Bay.

This morainic system on the slope toward Lake Michigan and Grand Traverse Bay differs in one striking particular from its expression on the slope toward Lake Huron. The outer moraine of the Lake Michigan portion is a distinct narrow ridge paralleled throughout much of its length by a second definite ridge, from which it is separated by the outwash and border drainage connected with the second ridge. Morainic spurs such as occur on the Huron slope are also conspicuous on the Lake Michigan slope, but they are related to the second instead of to the outer ridge of the system. The striking parallelism of these ridges is thought to indicate that the second ridge is a close successor of the outer one and a part of the same system.

The second ridge is practically continuous from eastern Charlevoix County southwestward to the head of Grand Traverse Bay. Southwest from Grand Traverse Bay, however, it consists of a broken chain of ridges leading across eastern Benzie County through an extensive gravel plain, from the western side of which prominent transverse ridges extend across southwestern Leelanau, Benzie, and Manistee counties to the shore of Lake Michigan, southwestward from Little Traverse Bay to Grand Traverse Bay, and on the borders of the latter conspicuously developed drumlins and drumlinoidal ridges lead either into the second moraine or somewhat later morainic ridges on the inner border of that moraine.

On the Huron as well as the Lake Michigan slope great depressions extend back between the morainic spurs and transverse ridges to the inner border of this morainic system. Several on the Lake Michigan slope are occupied by narrow, deep lakes, and such lakes also occur on the Huron slope in Cheboygan County and northern Alcona County, but others are occupied by

sandy plains. It is probable that these great depressions were occupied by tongues of ice during the decadence of the ice sheet. (See p. 315.)

In northeastern Manistee County the outer moraine is split into several members which become successively lower from east to west and which with the intervening plains give a step-like appearance, the morainic slope forming the riser and the gravel plain the tread.

The broken ridges leading from Manistee to Muskegon County show great variations in strength, their relief ranging from about 150 feet above the bordering plains down to swells 10 to 20 feet high. The most prominent are south of Ludington and in southern Manistee County.

RELIEF.

On the outer border the moraine which marks the limit of glacial readvance has (somewhat surprisingly) a general relief of only 20 to 40 feet above the table-land outside. The crest of the moraine is close to its outer edge and the knolls along it are only 15 to 30 feet high. Similar small knolls are distributed over the surface of the great spurs on the inner slope.

The second ridge on the Lake Michigan slope is also inconspicuous on its outer border, in most places rising only 10 to 20 feet above the narrow gravel plain that lies between it and the outer ridge. In this respect it contrasts strikingly with the inner border relief of the outer ridge, which is 150 to 200 feet along much of its course from northwestern Otsego County to the crossing of Manistee River east of Manistee. The gravel plain is like a terrace built up along the slope at a level 150 to 200 feet below the crest of the outer moraine.

On the inner border the relief is generally great. The spurs and ridges stand 150 to 300 feet or more above the intervening depressions.

STRUCTURE OF THE DRIFT.

The surface portion of the drift, as exposed in ravines, road gradings, and other shallow excavations, is largely till with a liberal admixture of stony material. Bowlders are rather numerous both on the surface and in the upper part of the till. The wells and deep ravines indicate that the stony till changes to sand at moderate depths along a considerable part of the morainic system, and, in the inner border district, especially on the Lake Michigan slope, to a fine silt or clay, which bears some resemblance to a lake deposit. (See p. 314.) The glacial material referable to this readvance of the ice forms therefore but a thin coating over water-laid deposits of great depth.

The color of the till shows considerable variation, some of it being distinctly red and other parts brown or yellow in the oxidized portion and blue in the unoxidized. The red color appears to be due to the incorporation of material from red rock formations in the Lake Superior basin and not to high oxidation in postglacial time. The red portion is about as calcareous as the brown and yellow. Where the underlying rock formations are of limestone or blue shale, as in the district between Little Traverse and Grand Traverse bays, there is less red drift than in neighboring districts to the north and south, where these rock formations are so deeply buried as to have made little or no contribution to the material in the till. It is not improbable, therefore, that local limestone and shale have served to give the brown and blue tills a distinctive color and to disguise the ingredients derived from the red rock formations.

On the Wisconsin side of Lake Michigan the correlative drift material is generally red. It also contains a much larger amount of fine silt or clay than is present in the surface portion of the drift on the east side of the lake or in ordinary bowlder clay. It seems to be largely derived from lacustrine silts, which were gathered up and redeposited by the ice with the addition of a little stony material very irregularly distributed.[1] Chamberlin made reference to this deposit in his work on the geology of Wisconsin and interpreted it to be the product of a lacustrine submergence that followed the retreat of the ice. Alden, however, has determined that it

[1] Two mechanical analyses of samples collected by Alden near Fond du Lac, Wis., made by the Bureau of Soils, United States Department of Agriculture, in 1910 show 41.3 and 51.5 per cent, respectively, of material below 0.005 millimeter. A lacustrine clay from Sauk County showed 46.9 per cent, and two samples of the buff-colored ordinary Wisconsin till near Oshkosh show only 8.2 and 7.6 per cent. It thus appears that the red drift is largely made up of fine lacustrine material.

was laid down in large part by ice and that its limits mark the extent of the glacial readvance. The red color is as pronounced in Wisconsin as in the reddest phases in Michigan. The path of the ice which reached Michigan on this interpretation seems to have led through less heavy deposits of lacustrine silt than that which reached the Wisconsin side of the Lake Michigan basin. Possibly the Michigan side owes the redness of its material entirely to the incorporation of material derived directly from the rock formations in the eastern part of the northern peninsula.

OUTWASH.

The outer moraine is accompanied by a broad outwash apron, one of the best developed in Michigan. Its general width is 5 or 6 miles and it is present along nearly the entire length of the outer moraine from eastern Oscoda County around to the border of Lake Michigan in Mason County.

Numerous small basins and some large ones lie in this gravel plain, and some of them contain lakes. Otsego Lake, one of the largest lakes in the interior of Michigan, lies south of Gaylord, partly in this outwash apron and partly in a depression between drift ridges of earlier date. Possibly this lake is in a valley that was blocked at the north by the deposition of the outwash.

Outside the second moraines from the reentrant angle between the Michigan and Huron lobes near the corners of Charlevoix, Cheboygan, and Otsego counties the drainage was directly southwestward to the bend of Boardman River in southern Grand Traverse County through a plain ranging in width from 2 miles to about 8 miles. From Boardman River the drainage continued southwestward past Interlochen and down Betsey River to Thompsonville, where it turned southward down Bear Creek valley to Manistee River, and then led southwestward through a series of gravel and sand plains that follow the line of the moraine. The material in this outwash belt is fine gravelly sand, very little coarse gravel being present in the line of the main channel. In the recesses west of Traverse City the outwash is in places of coarse material, indicating vigorous discharge, as might be expected from the steepness of the descent. The altitude in the reentrant angle exceeds 1,200 feet, and the glacial drainage channel drops to about 1,000 feet at Kalkaska in a distance of 30 to 35 miles, to 800 feet in the next 40 miles, and to about 700 feet in 20 miles more. This drainage, it should be remembered, is in a region which has suffered northward differential uplift (see pp. 430, 439) of 75 to 100 feet between the southern and northern ends of the channel, which would reduce the original rate of fall about 20 per cent. The effect of the high gradient is probably largely offset by the breadth of the tract through which the waters found their passage. They were probably split up into several streams of relatively small volume and were lacking in vigor notwithstanding their rapid descent.

Southeastward from the reentrant angle the drainage seems to have made its way through gaps among the morainic tracts of northeastern Otsego, central Montmorency, southwestern Alpena, and central Alcona counties to join the border drainage on the northwest side of the Saginaw lobe. These gaps are filled with fine sandy material deposited apparently under ponded conditions or by rather sluggish streams.

INNER BORDER.

HURON SLOPE.

DISTRIBUTION OF MORAINES.

Several ridges of morainic type lying some distance north of the morainic system trend northwest and southeast, approximately parallel with the main system, but no continuous morainic belt traverses the entire length of the northern Huron slope. The isolated short morainic ridges lie so far out of line as to make their correlation with one another uncertain; in fact they seem likely to have been developed at different times in the retreat of the ice border. Some are arranged in an overlapping series, showing successive development instead of strict contemporaneity. A series of three lies in southeastern Cheboygan and southwestern Presque

Isle counties. (See Pl. VII.) Southwest of Rogers, in Presque Isle County, there is also a double moraine of considerable prominence, yet neither member can be traced for more than 7 or 8 miles, both fading out into sandy plains or gently undulating till tracts.

North of Burt Lake a very prominent moraine has points that reach 900 feet and a breadth of 3 to 4 miles. North of this and separated from it by only a narrow sand plain a narrower morainic ridge rises above the 800-foot contour. A complex system of disjointed ridges extends from Mullet Lake southeastward across Cheboygan and Presque Isle into Montmorency County, the highest rising above the 900-foot contour. North of Black Lake in eastern Cheboygan and northwestern Presque Isle counties a very conspicuous morainic belt about 5 miles long rises above the 800-foot contour. Much of the double moraine southwest of Rogers also rises above the 800-foot contour. From northern Presque Isle County southeastward into southeastern Alpena County the morainic topography shows very little development, but west of Devils Lake, in southeastern Alpena County, a conspicuous moraine sets in and is traceable southeastward to Harrisville and thence southward nearly to southern Alcona County as a land-laid moraine. Farther south its expression is much milder, and it appears to have been formed at the border of Lake Warren (p. 392). It probably finds a continuation southward in either the Bay City or Tawas moraines, but the great width of the gap at Au Sable River makes correlation difficult.

The surface of the prominent morainic belts just noted presents a close aggregation of knolls and basins which give the moraines strong expression. It seems remarkable that moraines having such strong relief and such strong surface expression should be so discontinuous or have such fragmentary development.

From a point west of the middle of Devils Lake the inner slope of this moraine is heavily cut, producing a great bluff extending most of the way to Harrisville. This cutting has been attributed by the authors solely to the waves of Lake Algonquin, but it is perhaps a question whether it may not be due in part to a river flowing between the ice and the moraine, as was the case at Romeo and probably at Gagetown. (See pp. 284, 300.) The locality was studied before those at Romeo and Gagetown and has not been revisited.

Most of these morainic ridges consist largely of loose-textured drift, with considerable stony as well as sandy material. Clayey till is developed in only a few places, commonly on the inner or northeast slope of the morainic ridges. There is, however, considerable clayey till in the prominent morainic line in southeastern Alpena and eastern Alcona counties.

CHEBOYGAN MORAINE.

A very narrow morainic ridge scarcely one-fourth mile in average width, known as the Cheboygan moraine, is traceable from Cheboygan northwestward to Mackinaw City along the south side of the Straits of Mackinac, half a mile to a mile back from the shore. The ridge is also traceable eastward from Cheboygan for about 3 miles through the southern part of secs. 5, 4, and 3, T. 37 N., R. 1 W., and the ice border appears to have continued east-northeastward to the south part of sec. 32, T. 38 N., R. 1 E., as an ice-contact face between a bowldery till plain and a high sand plain to the south. Bowldery strips which run eastward for several miles farther probably represent the continuation of the border of the ice; their mapping is incomplete, but they are known to extend into the north part of T. 37 N., R. 2 E., Presque Isle County. The portion of this moraine and bowldery area east from Cheboygan lies within 3 miles of Lake Huron, at a very slight elevation above the lake level.

Although this moraine was formed at a level much below that of Lake Algonquin, the beaches of which are found on the uplands a few miles to the southwest, it is a remarkably distinct ridge, with well-defined knolls and greater irregularity of surface than is common in a water-laid moraine. It apparently marks the southern edge of a lobe of ice which came into the northern end of the Huron basin from the northern peninsula of Michigan and appears to be the youngest moraine on the southern peninsula.

ESKERS.

Several short eskers were noted in the reconnaissance made on the Huron slope in Cheboygan, Presque Isle, and Alpena counties. With the exception of one in central Alpena County, which is about 10 miles in length, none were observed which exceed 3 miles. It is not improbable, however, that the mapping of eskers is incomplete; it is difficult to trace such small ridges through forested areas, and the lines traversed by the writer were at such wide intervals that eskers might easily be present in the intervening tracts without being observed.

The esker in central Alpena County sets in at Thunder Bay River about 2 miles east of Long Rapids and runs southward through T. 31 N., R. 6 E. For a couple of miles at the northern end it has considerable complexity, there being in places three ridges side by side. It shows also a plexus of ridges in secs. 2 and 11, T. 30 N., R. 6 E. Its highest part is in secs. 2, 10, and 11, T. 30 N., R. 6 E., where points stand 50 to 75 feet above the bordering plain; but its ordinary height is about 25 feet. It trends west of south and terminates in the northern end of a great morainic tract which crosses southwestern Alpena County. This trend differs from that of the drumlins to the east, which bear north-northwest and south-southeast, but it nearly agrees with that of two drumlinoidal hills to the west. It seems not unlikely, therefore, that the esker represents the direction of the ice movement in the district which it traverses. Its northern portion has been opened at several places for gravel, which is found suitable for road ballast. Its southern end is somewhat more sandy and is less extensively opened.

An esker about 3 miles in length leads southward from La Roque station on the Detroit & Mackinac Railway through sec. 31, T. 34 N., R. 5 E., and secs. 6 and 7, T. 33 N., R. 5 E., its course being 20° to 25° east of south. It is a nearly continuous, very sharp ridge, about 30 feet in height, composed of fine gravel apparently suitable for road ballast.

About 5 miles west of La Roque a very prominent gravelly ridge is crossed by the Detroit & Mackinac Railway in a cut nearly 75 feet deep. This ridge is more massive than the ordinary esker and has an irregular surface much like a moraine, but seems to be composed almost entirely of gravel and sand. It runs southward from the railway about 3 miles along the east side of Oqueoc River and occupies a width of about one-half mile. Farther south a rolling gravelly belt of still greater width leads through the western part of T. 33 N., R. 4 E., with a trend very nearly the same as that of the La Roque esker. It may therefore mark the course of subglacial drainage as an esker does.

Some small eskers cross the State road from Onaway about 8 miles west of that village in the northeast part of T. 34 N., R. 1 W. The easternmost runs a little east of south through the SW. ¼ sec. 1. West of it a very prominent esker with similar trend was traced northward a little beyond the township line from sec. 2 into sec. 35. Possibly both eskers are continued beyond the limits noted.

DRUMLINS.

Two widely separated drumlin areas lie on the Huron slope, one being east of Mullet Lake in Cheboygan County and the other 50 to 60 miles to the southeast in central Alpena County. None were noted in the intervening district, but as it is a forested region and was not closely traversed, some may yet be discovered.

The drumlins east of Mullet Lake are in secs. 4, 5, 8, 9, 15, 16, 21, 22, 23, and 27, T. 36 N., R. 1 W., opposite the northern part of the lake. They are only 15 to 20 feet in height, less than a mile in length, and but one-eighth to one-fourth mile in width. They trend northwest and southeast, or nearly parallel to the neighboring morainic ridges. They are in a low tract considerably below the level of Lake Algonquin and must have been covered by the waters of that lake after the ice had receded from this region. They are composed of a stiff clayey till, and their surface, as well as that of the intervening sags, is thickly strewn with bowlders, which seem to have been deposited during the recession of the ice, being confined chiefly to tracts in which till is at the surface and being very scarce on the sandy tracts.

The other drumlin area lies a few miles west of Alpena, in central Alpena County, in a till plain west of the south branch of Thunder Bay River, at a level slightly above that of the highest

beach of Lake Algonquin. The majority of the drumlins lie 6 to 10 miles southeast of Flanders, but a few are in the immediate vicinity of that hamlet. Those near Flanders rise 40 to 60 feet above the bordering till plain; most of those to the southeast rise but 15 to 20 feet above it, though some, near the northern end, rise 35 to 40 feet. The trend of most of the drumlins is north-northwest and south-southeast, but those near the southeastern end bear more to the east. The trend is about in harmony with that of neighboring striæ west and north of Alpena. It is somewhat remarkable that both drumlins and striæ bear about parallel with the moraines which lie a few miles farther west. The ice movement appears, therefore, for some unknown reason, to have been less definitely directed toward those moraines during the development of the drumlins and the striæ than is common. The drumlins are composed of clayey till and their surfaces, as well as that of the surrounding till plain, are thickly strewn with bowlders.

GLACIAL STRIÆ.

The majority of observations of striæ in this region are in Alpena County, where general southeastward movement is recorded, though one observation of southward-bearing striæ was noted a few miles east of the northwest corner of the county. A single observation made in Cheboygan County, a few miles southeast of Mackinaw City, gives a movement of S. 37° W., directly toward the Cheboygan moraine, which passes just south of the striated ledge.

LAKE MICHIGAN SLOPE.

MANISTEE MORAINE.

The Manistee moraine appears on the east side of Lake Michigan, near the city of Manistee, and follows the shore northward through Manistee and Benzie into Leelanau County. It wraps around the western end of the prominent transverse ridges which come out as headlands along this part of the shore (pp. 303–304). Between these transverse ridges the ice pushed into the lowlands for several miles from the shore of Lake Michigan, so that the moraine makes a series of loops in crossing the lowlands between the prominent ridges. Its appearance is as if the ice had made a readvance and had adjusted its border to these topographic features. The portions of the lowlands overridden by the ice are coated to some extent with till, and in some places contain lakes, the most conspicuous being Crystal, Glen, and Portage lakes. The parts of the lowlands outside the Manistee moraine are covered with sand, apparently deposited from outwash that led eastward or southeastward into the drainage of Betsey River and Bear Creek. Some of these sand plains are 20 to 30 feet or more below the level of the outwash aprons that border the eastern ends of the prominent transverse ridges, apparently indicating that the outwash aprons were eroded before the Manistee moraine was developed. It is possible, however, that a large part of this erosion was due to waters escaping from the edge of the ice either during its recession from the outwash aprons or just preceding the filling which accompanied the development of the Manistee moraine.

The altitude of the Manistee moraine is scarcely 100 feet above Lake Michigan in the vicinity of Manistee, but it rises gradually northward and is fully 200 feet above the lake level at the eastern end of Crystal Lake, in Benzie County, and becomes still higher in southwestern Leelanau County. It there becomes more closely blended with the main morainic system, causing some uncertainty as to its line of continuation around Grand Traverse Bay. It seems likely to be merged with the earlier moraines at the outer edge of the drumlin area of the Grand Traverse region in Antrim County. The altitude there is only 200 to 250 feet above Lake Michigan and is thus consistent with the altitude attained by the Manistee moraine in western Benzie County; and, were it not that morainic developments are found in a few places nearer the shore, there apparently would be no cause to question this as the line of continuation of the Manistee moraine.

One of the best-defined loops sweeps around the head of Suttons Bay on the west side of Grand Traverse Bay, and then runs south along the west side of the latter bay nearly to Traverse City. It is from a fourth of a mile to a mile in width and stands only 100 to 150 feet above

the level of the bay, or about 100 feet lower than the Manistee moraine in the same latitude on the coast of Lake Michigan. At the head of Suttons Bay it has a well-defined outwash apron on its outer or southwest border and thus bears good evidence of being a terminal rather than a submarginal feature. A more prominent moraine north of Suttons Bay may have been formed between the Lake Michigan lobe and a branch occupying Grand Traverse Bay; this interpretation seems supported by the bordering features on the west, there being a till plain on that border that apparently was covered by the Lake Michigan lobe while this moraine was being developed. This moraine may in places reach a height as great as the Manistee moraine of southwestern Leelanau County, but its altitude is generally lower. The entire morainic strip on the west coast of Grand Traverse Bay is rather low to correlate well with the Manistee moraine and seems more likely to have been developed somewhat later as the ice shrank to a lower position. In that case it may be a close successor of the Manistee moraine.

On the peninsula between the arms of Grand Traverse Bay, as well as along the east coast of the bay, the topography is largely drumlinoidal rather than morainal down to levels corresponding to the moraine on the west side of the bay. Only near the southern end of the east side of Torchlight Lake does good morainal development appear. East of the south end of Torchlight Lake and northward on the east side of Clam Lake to the vicinity of Bellaire a moraine, which is thought to be a correlative of the Manistee moraine, is separated from the second moraine of the main system by a distinct outwash apron. This outwash apron, as well as the moraine, is much lower than the second moraine and its outwash, the moraine being 200 to 300 feet above Lake Michigan and the outwash apron about 200 feet, whereas the higher moraine and outwash have an altitude of 500 feet or more. Southeast of Clam Lake the moraine for 3 or 4 miles is only about one-fourth mile in width, but it has a relief of nearly 200 feet on its inner or western border. It is at this narrow part that the outwash apron is best developed. This moraine is not clearly differentiated from the earlier moraine around the head of Grand Traverse Bay nor in the district north of Bellaire.

On the north border of Little Traverse Bay a weak moraine, rising about 200 feet above Lake Michigan level, is in part banked against a much higher morainic accumulation and in part runs across the south end of a lowland east of this prominent moraine near the east end of Little Traverse Bay. This moraine seems to have been formed by a narrow tongue of ice that pushed eastward from Lake Michigan into Little Traverse Bay and terminated a short distance beyond the head of the bay. There is not so definite a moraine along the south side of the bay, yet in places some ridging of the drift forming a drainage divide parallel with the shore was noted. This moraine like the moraine on the west side of Grand Traverse Bay seems rather low to be correlated with the Manistee moraine, but it may be a close successor of that moraine, the precise correlative being a moraine on the edge of the tract with drumlinoidal ridges a few miles southeast of Little Traverse Bay.

The Manistee moraine probably correlates with one of the chains of morainic ridges on the Huron slope, presumably with the highest chain that has a southeastward trend. This probably should include the high morainic tracts of northern Emmet and northwestern Cheboygan counties as well as those which lead southeastward from near the south end of Mullet Lake. It may also correlate with the moraine that follows the Huron shore past Harrisville and possibly with either the Bay City or the Tawas moraine farther south and thus correlate with the closing stage of Lake Warren. Unfortunately the fragmentary development of moraines on the Huron slope leaves the exact correlation doubtful.

CORRELATIVES OF THE MANISTEE MORAINE IN WISCONSIN.

Grounds for the definite correlation of the Manistee moraine with a moraine which sets in directly opposite Manistee near Two Rivers, Wis., and leads northward along the west coast of Lake Michigan, are found in the peculiar relation of each of these moraines to the beaches of Lake Chicago. It was noted some years ago that only the third or Toleston beach of Lake Chicago is present on the slopes of the Manistee moraine, and that higher beaches are present on the earlier moraines that border Lake Michigan farther south. Similar conditions were found

by W. C. Alden and the writer in the moraines in eastern Wisconsin during a field conference in September, 1910. The moraine leading north from Two Rivers has no beach higher than the third beach of Lake Chicago, which is there about 25 feet above Lake Michigan. But within a few miles south of Two Rivers, on the plain between the lake and one of the earlier red drift moraines, beaches and river deltas are developed up to about 60 feet above Lake Michigan. There could scarcely be better grounds for correlation than are presented in the relation of these moraines to the Lake Chicago beaches.

ISLANDS IN THE NORTHERN PART OF LAKE MICHIGAN.

Several prominent islands lie some miles off the eastern shore of Lake Michigan, the largest being Beaver Island and the two Manitou islands. The Fox Islands lie between these, and several other islands lie near the north end of Beaver Island. North and South Manitou and Beaver islands carry heavy accumulations of drift with morainic surface. The other islands are more largely formed of sand, and those near Beaver Island have slight outcrops of rock. North Manitou Island has two high rugged north-south morainic ridges which merge at the southern end of the island but are separated by a low tract containing a lake near the northern end. Much of South Manitou Island is somewhat less prominently morainic. Mr. Taylor reports that on Beaver Island morainic ridges trend northwest and southeast in the north and southeast parts of the island, as if formed by ice from the east, but that an area of seemingly interlobate deposition with basins and ponds lies to the southwest. All these island moraines are probably later than those formed on the mainland unless the moraines on Beaver Island correlate with the Cheboygan moraine of the Huron lobe. Correlation across such wide strips of water is very uncertain, and the morainic features of the islands will be left with this passing notice.

DRUMLINS IN THE GRAND TRAVERSE AREA.

Distribution.—Drumlins are best developed in the district between Grand Traverse and Little Traverse bays, though a few well-developed drumlins and numerous drumlinoidal hills lie west of Grand Traverse Bay and a few drumlinoids north of Little Traverse Bay near Levering. Drumlins occur for about 25 miles inland from the borders of Lake Michigan and at all altitudes from 20 feet up to 300 feet above the level of the lake, or from 600 to about 900 feet above sea level. They are confined almost entirely to the uplands and slopes, though near Elk Rapids some were found on the low plain bordering Elk Lake. At the southeast border of the district the drumlins are closely associated with morainic knolls, and in places may be said to grade into them, some hills having a well-rounded drumlin form at their northwest end and a hummocky topography at their southeast end. Features of this sort are found on each side of the southern part of Pine Lake, and also on the borders of the south end of Intermediate Lake, both east and west of Bellaire, and thence northeastward toward the south arm of Pine Lake. From Pine Lake to Little Traverse Bay a gradual change takes place from well-defined drumlins to drumlinoidal ridges and then to elliptical but irregular-surfaced hills such as immediately border the city of Petoskey. The drumlins show their most characteristic form in the district between Pine Lake and Torchlight Lake. (See fig. 2.) Most of the ridges between Torchlight Lake and Grand Traverse Bay, as well as those on the peninsula in the bay and on the peninsula between Grand Traverse Bay and Lake Michigan, are drumlinoids rather than true drumlins, their shapes being very imperfect and their surfaces but slightly smoothed. They are, however, similar in trend and in general shape to the well-formed drumlins and are separated from each other by the smooth sags generally present among drumlins.

The drumlins vary in shape from oval forms, whose length is about one and a half times their width, to linear ridges, whose length is six to eight times as great as the width. (See figs. 2 and 3.) The great majority, however, are one-half to three-fourths mile long and one-eighth to one-fourth mile wide. The longest reach 1½ miles. Some large drumlins have fluted slopes and resemble a small drumlin perched on a sculptured large one. Such forms are to be seen on the borders of the south arm of Pine Lake (fig. 3) and in the district between Torch-

light Lake and Grand Traverse Bay. The height of few of the drumlins exceeds 60 feet and that of the majority is 30 feet or less. The smallest are only 10 to 15 feet high.

The drumlins trend south or but slightly east of south on the borders of Grand Traverse Bay, but change gradually to southeastward in the district around Pine Lake (fig. 2), corresponding very rudely to the great valleys and ridges of the region. The greatest discordance is with the south arm of Pine Lake and the west arm of Intermediate Lake, which trend south, whereas the adjacent drumlins trend considerably east of south.

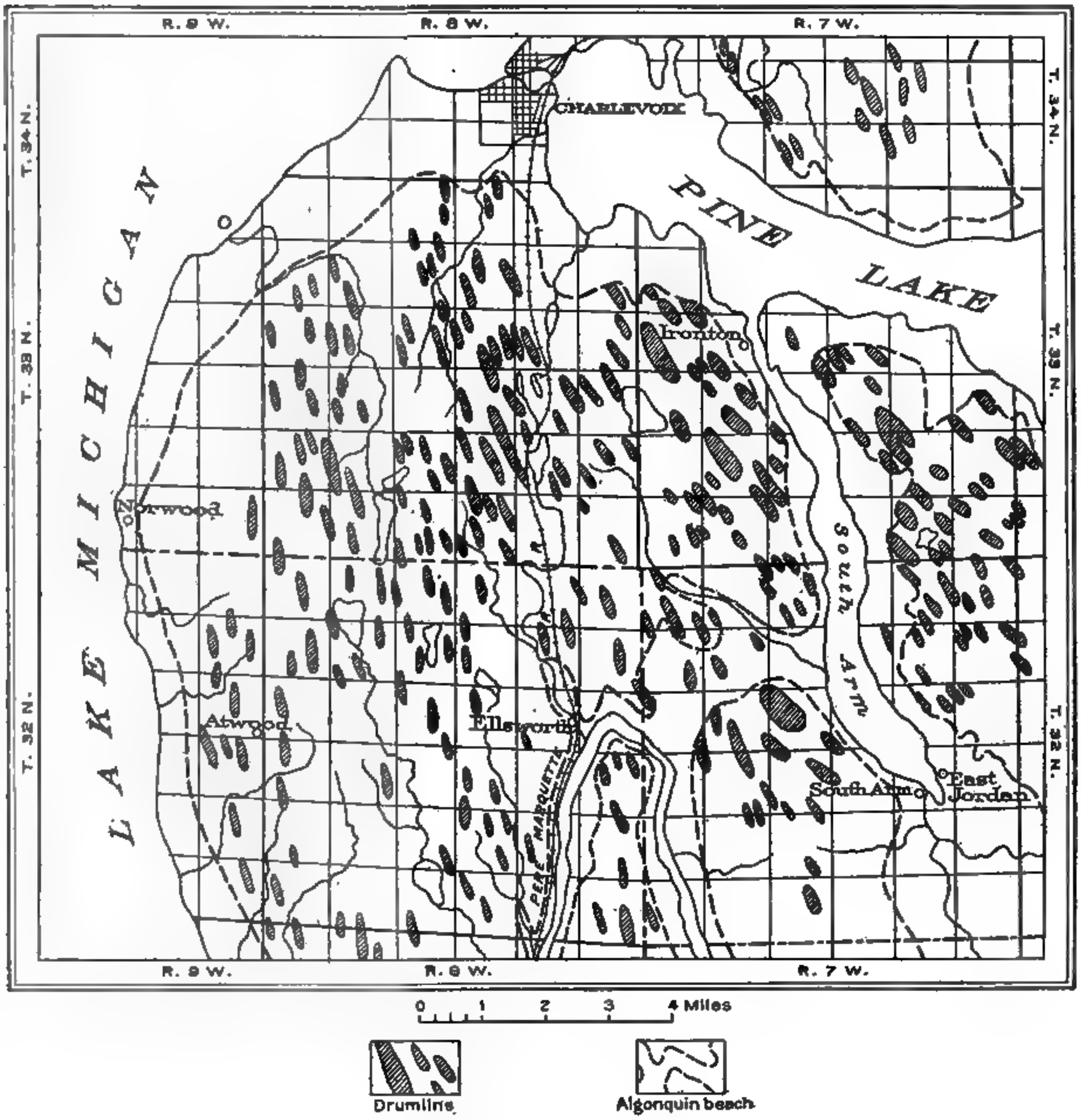

FIGURE 2.—Map of part of drumlin area south and east of Charlevoix, Mich.

Origin.—The drumlins are composed of a very evenly mixed stony till, stones being distributed through almost every cubic inch of the deposit. The majority of the stones are small, but some bowlders were noted and small rock slabs are not rare. In most of the exposures the till shows indistinct partings rudely concentric with the surface. The rock slabs do not show, as in ordinary till, all sorts of deposition from vertical to horizontal, such as result from dropping into a deposit, but lie in the plane of the deposits, as if carried by the ice across the

surface of the drumlin until lodged in a position that offered least resistance to the ice movement. Most of them show on both their upper and under surfaces striation whose direction generally coincides somewhat closely with the trend of the axis of the drumlin. The position of the rock slabs, the indistinct bedding of the deposit, and the thorough admixture of pebbles seem to bear evidence to the growth of the drumlins by slow accretion.

In certain situations, however, evidences are not wanting of sculpturing of the till into drumlin form. Shale hills, which have been shaped into drumlinoid form as a result of the ice movement over them, are found south of East Jordan in northern Echo Township, Antrim

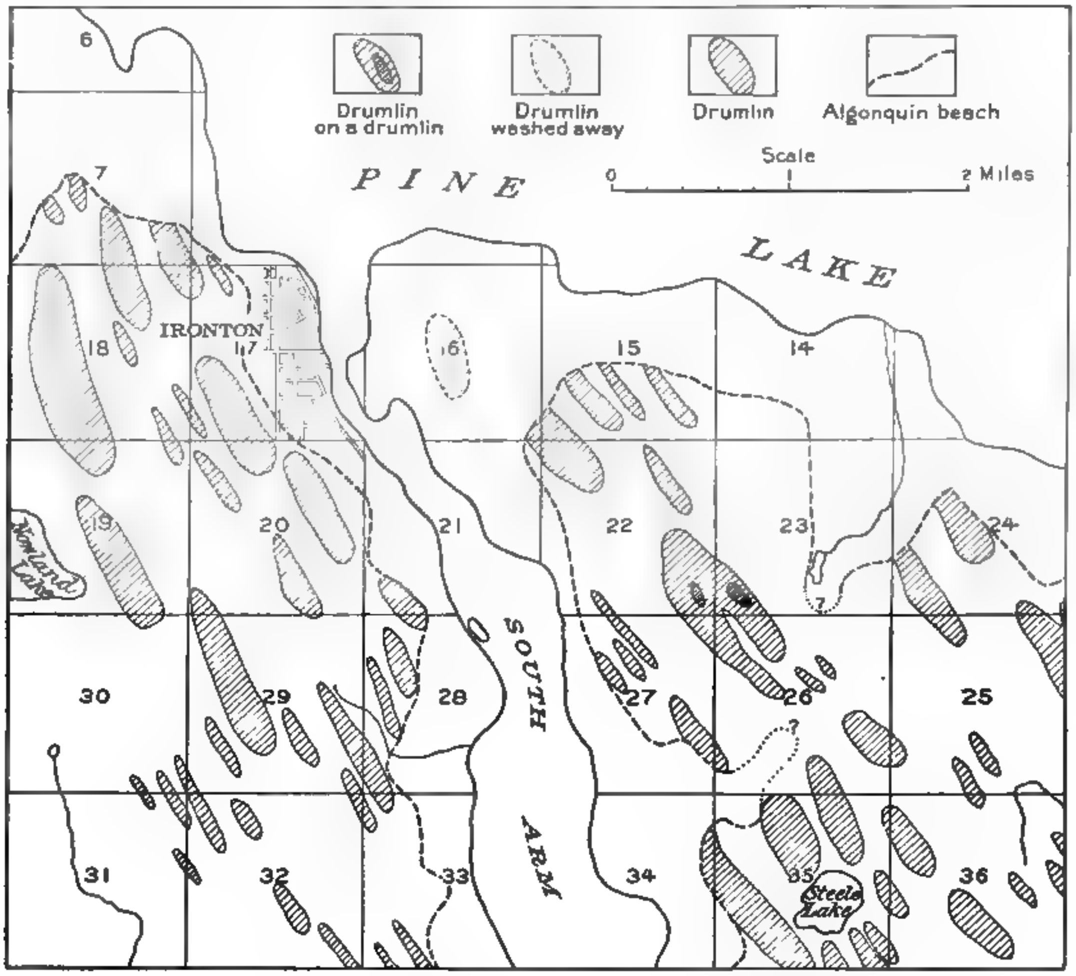

FIGURE 3.—Drumlins in T. 33 N., R. 7 W., Charlevoix County, Mich.

County. A till drumlin near these shale hills is partly encircled at its northwest end by a crescentic groove several feet in depth which appears to have been formed by the ice as it met the obstruction presented by the drumlin, just as similar grooves are formed on a striated surface on the stoss side of slight prominences on a rock surface. When the ice struck the drumlin it appears to have intensified its action on the plain at the base of the drumlin and thus produced the deep furrow. The flutings which some drumlins display seems likely also to be due to sculpturing effect of the ice. The drumlins which show fluting and sculpturing are restricted chiefly to places where the ice was making a rapid ascent. In places where the general slopes are down-

ward, or where the drumlins lie on a horizontal surface, the lamination and evidences of building up by slow accretion are best displayed. It thus appears probable that the attitude of the surface passed over by the ice determined to a large extent the method of drumlin formation.

After the above description of the drumlins was written Alden presented a paper before the Pittsburgh meeting of the Geological Society of America, an abstract of which has reached the writer, in which he discussed radiation of glacial flow as a factor in drumlin accumulation. Radiation was about as marked in the Grand Traverse region as it was in the Green Bay region studied by Alden, so the drumlins under discussion may have had a like origin. The Grand Traverse region, however, does not afford so good a field as the Green Bay for testing the hypothesis. The abstract presented by Alden is as follows:

This discussion is based on the relations of the moraines and drumlins of the south half of the Green Bay glacier of eastern Wisconsin. There is a very notable development of drumlins which are grouped in three more or less distinct sets. Corresponding to each is a set of marginal moraines believed to mark the limits of the glacial lobe during the stages when the drumlins were being formed. The outer moraine of each set marks the limit of a readvance of the ice following an interval of recession. The drumlin belts in each case are confined to distances of 30 to 35 miles from the south end of the lobe, that is, to that part where the ice was radiating widely to the curved margin of the lobe and where it was thinned in consequence of the radial spreading and of loss by melting and ablation.

The computations of the probable elevation of the surface of the glacier were based on the known thickness of the ice within 4 miles of the margin where the Baraboo quartzite range was overridden and on an estimated average slope for this surface of 50 feet per mile in the first 25 miles, including the initial rise of 700 feet in the first 4 miles and allowing an average of 20 feet per mile thereafter. Deducting from these the present elevation of the land gives a thickness of ice varying from 1,450 feet over the initial part of the first drumlin belt to 450 to 830 feet where drumlins ceased to be formed within 5 miles of the limit of ice advance. The drumlin-forming ice stream had an initial width at A of 17 miles where radiation began. In advancing 15 miles this expanded to a width of 32 miles at B and at the terminal moraine the expansion gave a marginal arc of about 100 miles. Computations show that in spreading to the width at B, while at the same time maintaining the requisite thickness and low surficial slope, the cross section of the stream must have increased to 1.603 times the area of the initial section and, inasmuch as no tributary stream had added to the volume, the rate of flow must have been faster at A than at B. At C, where the drumlin formation ceased, the arc of the stream had expanded to 85 miles and the cross section was 2.325 times that at A and 1.45 times that where drumlin formation began. From these figures it is evident that the spreading of the ice under its own weight alone would not account for the remarkable expansion. Only the forward crowding of the more rapidly moving ice in the rear could have supplied the requisite volume. Though the stream expanded greatly so that friction was much increased, the remarkable development of drumlins indicates that the basal ice did not clog. Such basal movement was probably due to the ice being shoved bodily forward by the vigorously advancing ice in the rear, this forward shove being superimposed on such internal flowage as was taking place. It is believed that the application of such propulsive force in the region of the center of radiation of such a mass, which was tending to lag in every part, owing to great friction, would tend to cause the longitudinal lines to spread and so develop stress along transverse lines. These stresses, though perhaps not causing the actual opening of longitudinal crevasses, would facilitate spreading of the ice about obstructing piles of drift and their being shaped into drumlins rather than their obliteration by erosion. It might also induce localized deposition in piles or ridges which would later be shaped and might be added to by the plastering on of drift. Computations based on the ice stream forming the second set of drumlins shows the radiation to have been even more marked than in the first case, with corresponding greater crowding forward of the faster moving ice in the rear and more marked development of drumlins. Comparison with segments of the glacier which had equal initial widths but did not form drumlins shows that in the latter there was very moderate radiation and that, unless the ice in the rear was moving more slowly than that in front, there was a decrease in the volume of the stream as it advanced, as opposed to the increase in volume of the drumlin-forming stream. With the radiation fully accounted for by the ice under its own weight and with no forward crowding of the ice in mass there would be absence of lateral stress and of the tendency to longitudinal crevassing, and this may explain the absence of drumlins. Other factors than radiation are probably involved.

Structure.—The material of which the drumlins of the Grand Traverse area are composed is in large part a reddish till. This is especially true of the drumlins in the region of least relief and especially in the district shown in figure 2, between the north part of Torchlight Lake and the south arm of Pine Lake, where the drumlins are the most numerous and best formed of any in this field. Southeastward toward the moraine a change takes place from clayey to loosertextured material, and the drumlins on the extreme southeastern outskirts of the field are generally very loose textured. This change in texture is a natural result of an approach to the edge of the ice, for more or less fine material is carried away from the ice border by the waters discharging from the border, thus leaving the coarser material to be deposited in the moraines and other deposits made near the edge of the ice. Pressure is also markedly less near the edge than

at several miles back under the ice, and where drumlin forming was going on this is likely to have been a potent factor in determining texture and compactness of the material.

BURIED LACUSTRINE (?) CLAYS OF GRAND TRAVERSE REGION.

Distribution.—Beneath the latest till deposits of the eastern coast of Lake Michigan from the vicinity of Frankfort northeastward nearly to the Straits of Mackinac there are frequent exposures of a clay which is nearly free from pebbles and which appears to have been deposited in water. In some of the exposures the clay is distinctly laminated and is evidently water deposited. In other exposures it was difficult to discover bedding planes, yet the absence or extreme scarcity of pebbly material renders the clay a doubtful glacial product. In a few places there are sandy partings between the layers of clay, and in such places the deposition in water is scarcely to be questioned. These clay deposits are present in the abrupt bluff-like borders of some of the deep valleys or valley-like lowlands which traverse this region. These lowlands ordinarily contain a great depth of loose sand, and it is not known whether this sand is underlain by the clay.

The altitude which the clay reaches beneath the crests of the ridges is difficult to determine. Exposures on the slopes of the ridges, by which it has chiefly been discovered, show it to be present south of Central Lake and southeast of Pine Lake in the vicinity of Boyne Falls up to an altitude about 300 feet above Lake Michigan, or 880 feet above sea level. West of Bellaire and near the northern end of the peninsula in eastern Emmet and western Cheboygan counties it was noted about 850 feet above sea level. Between Torchlight Lake and Grand Traverse Bay and on the peninsula between the arms of Grand Traverse Bay it is found up to a height of 800 feet or more. In the vicinity of Frankfort and northeastward past Crystal Lake and Platte River the highest exposures are between 680 and 740 feet above tide. Several exposures were noted in the vicinity of Benzonia. Exposures are good in Frankfort along the shore of Lake Michigan and also in excavations near the courthouse.

Structure and characteristics.—This laminated clay varies considerably in color In the vicinity of Frankfort, north of Pine Lake and northeast of Little Traverse Bay, it is red or pink. Along the east side of Grand Traverse Bay and near Central Lake on the west side of the west arm of Intermediate Lake much of it is drab or blue. The pink color seems likely to be due to the accession of ferruginous material from the formations in the northern peninsula, just as in the overlying till. The drab or blue is the ordinary color presented by deposits that have received no special contribution of red ferruginous material.

This clay is generally very calcareous, whatever its color. Much of it shows calcareous nodules and tubes on the face of the exposures. The deposit appears, therefore, to have received such a fine flour as is produced by the grinding of limestone formations by an ice sheet.

The thickness of the deposit differs widely, ranging from a few feet to 100 feet and possibly much more. The record of the boring at Elk Rapids suggests its presence to a great depth below the level of Lake Michigan, and exposures a few miles northeast of that village show its presence more than 200 feet above the lake.

Origin.—Much uncertainty exists as to the origin of this clay. Its range in altitude and its possible thickness are greater than seem easily attributable to ordinary lake action, and yet such may be the method of its deposition. Possibly before the ice made its final recession from this region the northern end of the southern peninsula of Michigan was low enough for the lake waters to cover all the places in which the clay has been found, although some of these are 300 feet above present lake level and about 200 feet above neighboring portions of the Algonquin beach, the beach of the first glacial lake that succeeded the final recession of the ice. Since Algonquin time there has been an uplift of only about 100 feet in the region bordering Little Traverse Bay, but there may have been a much greater pre-Algonquin uplift. The pre-Algonquin uplift, as shown in the tilting of the Arkona, Whittlesey, and Warren beaches, seems sufficient to support the view that if free from ice in Lake Arkona time the region in which these buried silts are present would have been covered by lake waters to about the extent which these silt deposits reach.

The deposition of the silt may prove, however, to have been not in an open lake of broad extent, such as the glacial Lake Algonquin, but in narrow strips of water between lobes of ice that occupied the great valley-like lowlands now occupied by the arms of Grand Traverse Bay, Pine Lake, Torchlight Lake, and lesser lakes of the Grand Traverse region. As noted above, the deposit is found in the narrow strips of upland between these basins and is not found on the immediate floor of most of the great valleys. Possibly it is not present beneath these valleys, if the ice lobes were occupying the valleys during the deposition of the clay. Buried as this deposit is beneath thick deposits of till so that it is exposed in very few places, there is necessarily such a dearth of data concerning it that its origin can not be cleared up at the present writing.

The time of its deposition compared with the overlying till is also a matter of uncertainty. It is not known whether it is contemporaneous with the ice occupancy of the valley-like depressions, or whether it was deposited in a time corresponding to Lake Arkona between the recession of the ice and the readvance just discussed, or whether it is an interglacial deposit laid down before the Wisconsin stage of glaciation.

On the supposition of its being a pre-Wisconsin interglacial deposit it would naturally be interpreted as a mere remnant of the original deposit with great gaps along the line of the valleys made either by the pushing of the ice into these valleys or by ordinary stream action in interglacial times, or to a combination of the two processes.

On the supposition of deposition during an ice recession within the Wisconsin stage there would be less chance for ordinary stream erosion, and the great removal of material along the valleys would be chiefly referable to the action of the readvancing ice.

On the supposition of contemporaneous deposition with ice lobes occupying the valleys the deposit may now have about its original extent. On this interpretation the deposition of the clay may have been during the waning of the ice prior to the last readvance. It may have taken place, however, during a possible readvance in which the ice protruded into the great valleys before covering the upland. This would be likely to cause a heavy silt deposition, not only from the edges of the advancing lobes but from the broad field of ice which was about to encroach upon the upland.

On the whole the distribution and character of the deposits and especially the freshness of their appearance are thought to favor their close connection with glacial agencies either during the waning or the readvance of the ice in the later part of the Wisconsin stage of glaciation.

CHAPTER XII.

OUTLINE OF GLACIAL AND POSTGLACIAL HISTORY OF THE GREAT LAKES REGION.

By FRANK B. TAYLOR.

The Great Laurentian Lakes, or the Great Lakes, as they are commonly styled, are a group of valleys which have been turned into lakes. Geologically speaking, the lakes themselves are new and youthful forms, although the valleys in which they lie are much older.

PREGLACIAL HISTORY OF THE GREAT LAKES BASINS.

STAGES OF DEVELOPMENT.

The basins of the Great Lakes were once valleys with free drainage and no lakes, like the Ohio Valley of to-day. The events which changed them into water-filled basins were apparently associated with the glacial epoch and are therefore of relatively recent date. It is the later part of the Great Lakes history, comprising the glacial and postglacial stages, that has most engaged the attention of students, because the facts relating to that part are the newest and most numerous. But in any comprehensive view the fact should not be overlooked that the Great Lakes, or rather the basins in which they lie, had a long and complicated history before the glacial epoch and also a complex interglacial history. Only the main outlines of the earlier epochs are known at the present time, and it will here suffice to enumerate them briefly.

The preglacial history of the Great Lakes is the geologic history of the region. For convenience it may be divided into three stages, each dominantly though not exclusively characterized by a particular phase of development. The first was the stage of sedimentation or Paleozoic strata building—the constructional stage; the second was the epoch of land elevation, causing increase of altitude and starting erosion—the stage of emergence; and the third was the stage of erosion or valley making—the destructional stage. These three stages are not sharply and completely marked off from each other, although they may appear to be so in some parts of the Great Lakes area. For example, in the northwestern part uplifts producing emergence of land areas occurred while in much of the region of the lakes farther east sedimentation was going on uninterruptedly. Whatever land was raised above the sea was attacked by erosion. Thus, to some extent, sedimentation, elevation, and erosion were all going on at one and the same time. But the successive dominance of the three processes distinguishes fairly well the three phases of development.

STAGE OF CONSTRUCTION.

It is well known that the basins of the Great Lakes lie chiefly in depressions that were formerly filled and completely occupied by Paleozoic strata. While these strata were being laid down the whole region, except perhaps part of the Archean area south of Lake Superior and some parts of the plateau north of the Great Lakes, was under the sea. The rocks that filled these basins have very different characters in different beds. There are conglomerates and sandstones, shales and limestones, and in some places igneous rocks. Each of these classes of rocks has many varieties with more or less variation in hardness and chemical properties, and these qualities exercised an important influence on the rate and manner of disintegration under the forces of erosion. The formation of the Great Lakes basins has thus been dependent

to a large degree on the character of the strata out of which they have been excavated—on their relative hardness, thickness, and arrangement.

This was the constructional period in which nature was getting ready for the subsequent making of the lake basins.

STAGE OF EMERGENCE.

The lake basins did not begin to be made until another great event in geologic history, involving a great change in the relative altitude of the land and sea, had taken place. Beginning at the close of the Paleozoic era great earth movements affected all of the eastern part of North America, including the whole of the Great Lakes region, lifting the land now occupied by the lakes to an altitude estimated by some to be 2,000 or 3,000 feet higher than its present altitude. This was the time of the uplifting and folding of the Appalachian Mountains. The process probably occupied some thousands of years, but in a geologic sense its duration was short.

There is evidence also of some earlier movements of less extent that affected the region of Lake Superior and especially the northern part of Lake Huron, and that probably produced small land surfaces.

STAGE OF DESTRUCTION.

The forces of subaerial and stream erosion attacked the surface of the land as fast as it was raised above the level of the sea, and the sea itself, with its waves and tides and currents, attacked the new shores. Rain and frost, wind and sunshine, and the agents of chemical decomposition attacked every part of the land surface. Most effective of all was the water that gathered into flowing streams. All of these, great and small, did their share of work in tearing down and sculpturing the new land, carving valleys, hills, and mountains out of the elevated mass. Each worked with an efficiency dependent upon its volume, the rate of its descent, the character and quantity of the sediment it carried, and on other factors. The first shapes of the newly emerged land determined the first drainage systems, but as the work of erosion went on, the effects produced were greatly influenced by the variously resistant characters of the rocks and their relative position and arrangement.

The strata out of which the lake basins were later excavated were laid down for the most part not along the shores of that ancient time but at some distance offshore, so that the sediments received were mainly of fine texture, mud which afterward became shale and limy ooze which afterward became limestone. Conglomerates and sandstones indicating shore or shallow near-shore conditions occur, but are not common. Limestone does not rank as hard in the mineral scale, but relatively to the shales some of it is hard and resistant, especially where it occurs in massive form and in great thickness. In the building of the strata it happened that a group (Niagara) of beds whose arrangement and relative hardness predisposed them to unequal erosion and to the formation of valleys bounded by great escarpments was laid down from central New York to northern Michigan. The limestone of this group, a massive bed of the hardest quality, 150 to 200 feet thick, is underlain by several hundred feet of the Clinton and Medina formations of shales and sandstones—chiefly shales—and thin layers of limestone much softer than the overlying limestone. It is overlain by 200 to 300 feet of the very soft, marly, salt-bearing beds composing the Salina formation. The selective processes of erosion led the streams to attack the softer strata and to wear them away, leaving the harder limestone of the Niagara group to form the great escarpment which now stretches from New York to Wisconsin. Extensive valleys were eroded in the soft underlying rocks, undermining the limestone and driving it back. Other valleys were excavated in the soft overlying Salina formation.

Thus Lake Ontario, Georgian Bay, the northern channel of Lake Huron, and Green Bay were excavated out of the soft rock below the limestone of the Niagara group; and Lake Erie, the main body of Lake Huron, and all of Lake Michigan were excavated out of the soft strata above the limestone. Lake Superior appears to be somewhat exceptional. It is thought to be

largely an original rock basin, or perhaps a syncline out of which soft rocks, probably in the main those below the limestone, have been eroded.

Thus, the shape and size and arrangement of the lake valleys were primarily dependent on the geologic structure—on the relative position and thickness of the soft beds and the distribution of their exposed parts. Where the soft beds were exposed to effective stream erosion they were removed more rapidly than the harder rocks and thus became the main valleys of the region.

In the present attitude of the land the Paleozoic strata dip distinctly but gently south in the basin of Lake Ontario; south in the eastern part and southwest and west in the western part of the basin of Lake Erie; southwest in the main part and south in the northwestern part of the basin of Lake Huron; south in the northeastern part and east in the southern part of the basin of Lake Michigan, and south in the peninsula east of Marquette; steeply north in the western part and variously in other parts of the basin of Lake Superior.

That these valleys were going through the process of development by erosion during practically all the time from the close of the Paleozoic to the beginning of the glacial epoch seems not improbable. Indeed, the time must have been very long to have permitted the making of such extensive valleys by so slow a process. It might be thought that some movement of elevation or tilting had turned these old valleys into lake basins long before the time of the ice epoch, but no certain evidence indicating such a change has been found. Up to or nearly to the beginning of the ice epoch the valleys appear to have had complete drainage by rivers and to have held no lakes. Although the whole region was probably reduced to a peneplain more than once in the long time of preglacial erosion, it appears to have stood at a relatively high altitude above sea level toward the close of that time. This is indicated by the deeper lake basins, by the submarine valleys of the St. Lawrence, the Hudson, and other rivers.

DIFFERENTIAL UPLIFT.

Some time before the beginning or possibly in the earlier part of the ice epoch, the northern lands were uplifted in such a way as to warp or tilt the region of these great valleys. The lands in the north were uplifted more than those in the south, and as the outflow of most of these valleys was northerly, their lower courses were elevated more than their headward parts, and they became water-filled basins or lakes. It is not known with certainty when the first important tilting took place. If the great period of diastrophism, which began in late Cretaceous time and reached a climax in the middle or later part of the Tertiary, was characterized by a southwestward creeping of the entire crustal sheet of the continent, as certain features seem to suggest, it may well be that the principal part of the warping which turned the open valleys into lakes occurred at that time and was the result of that movement. At present, however, the facts bearing upon this question are too few to warrant more than the briefest mention.

GLACIAL HISTORY OF THE GREAT LAKES BASINS.

EARLY STAGES.

The glacial epoch as a whole has been found to be made up of at least four distinct stages of glaciation separated by intervening warm periods when the ice sheet either shrank to relatively small proportions or disappeared altogether. The last ice sheet deposited what is known as the Wisconsin drift. There is abundant evidence, however, that the lake basins existed substantially as they are to-day during at least one of the earlier stages of glaciation. In the southeastern and central parts of the southern peninsula of Michigan there is a great body of older drift underlying the drift of the Wisconsin stage, and in the northern part of the same peninsula there are thick deposits of lake clays, which were deposited in the basin of Lake Michigan before the last advance of the last ice sheet, for they are overlain by drumlins of Wisconsin age. (See pp. 314–315.) Possibly they were deposited before the Wisconsin glaciation. The position and relation of these beds indicate that this part of the Lake Michigan basin was then in all respects the same as it is to-day, except that the water stood relatively somewhat higher upon the land;

and this seems to indicate that if the lake had a northward outlet then as now, the northern part of the basin stood relatively lower than now, for in its present attitude it lacks only 8 feet of overflowing at its southern end. It seems certain that the depressions which constitute the lake basins were involved in each one of the several glacial stages; and yet all the basins, except perhaps that of Lake Superior, retain very distinct characters which belong to stream-eroded valleys. Indeed, except for the drift deposits and the effects produced by tilting, they may almost be said to show no other characters. All the changes produced by the several glacial invasions have not destroyed these characters nor obliterated them to any great extent. In fact, when the last ice sheet crept from the north down into the lake basins it appears to have found them in almost every detail the same as they are to-day.

No doubt the events of the lake history which occurred during the advancing phase of the last ice sheet as well as in the earlier glacial stages are matters which would be of great interest and importance if they were accessible; but they seem destined to remain in obscurity, because the record made by the ice at the climax of each minor movement of advance was continually being overridden and obliterated by later and more energetic readvances; and further, in the region of the Great Lakes the drift sheets of the older glacial stages were almost entirely overridden by the later ones.

GREAT LAKES DURING AND AFTER THE RETREAT OF THE LAST ICE SHEET.

COMPLEXITIES OF THE HISTORY.

The retreat of the ice in the last or Wisconsin stage of glaciation marks the beginning of that later phase of the lake history whose records are so clearly and completely preserved in the present surface deposits. This part of the history is spread like an open book upon the surface of the lake region. An immense body of facts bearing upon it and giving a fairly full knowledge of its details has already been gathered, and continued exploration will afford many more.

This part of the lake history has its own complexities, arising from several causes: (1) The oscillating manner of the retreat of the ice border, which was accompanied by periodic minor movements of retreat and readvance; (2) the irregularities of topography which characterize the lake region; (3) the variation in the direction of the general retreat of the ice limit across the lake basins; and (4) the differential elevation of the land during and after the ice occupation, the maximum elevation occurring in the north and producing several changes of outlet.

The combined effect of these and other less important factors produced a complex history, not only as expressed by the distribution and relations of the various drift forms, but also by the remarkable effects of the ice sheet on the associated drainage. It determined the location of great rivers which flowed only temporarily from the ice or along its border and it caused remarkable shiftings of their courses. Its most noteworthy effect, however, was the production of a complex succession of shifting and changing lakes—enlarging, falling, shrinking, combining, dividing, and rising—of large extent and frequent changes of outlet, coming at last to the lakes as they are to-day. As investigation has inclined more and more to details and has covered an increasing area it has been found that the succession of changes involved in the later lake history is much more complex than was formerly supposed.

SHRINKAGE OF THE ICE SHEET INTO THE LAKE BASINS.

In one of its earlier stages (the Illinoian) the ice sheet covered the entire region of the Great Lakes, the only exception being the well-known Driftless Area which lies chiefly in western Wisconsin. This area is in the angle between Lake Michigan and Lake Superior, but does not comprise any part of the drainage basin of either one of them. As the ice sheet moved southward the lake basins naturally offered the easiest lines of flow and the high lands between the basins were areas of greater resistance and slower flow. But when the ice attained its maximum, reaching nearly to Cairo in Illinois, about 10 miles beyond Ohio River south of Cincinnati in Kentucky, and to Beaver Falls in Pennsylvania, the lake basins became relatively unimportant in their effect upon the ice movement, for at that time the ice overwhelmed them all, including

even the high lands between them. As it retreated, however, the relative importance of the lake basins in controlling the ice flow increased rapidly and by the time the ice front had withdrawn to the most southerly points of the watershed of the lake basins it had taken on lobate forms of a most pronounced type. In the latest or Wisconsin stage of glaciation the farthest extension of the ice did not reach so far south in the region west of central Ohio as it had before. In Illinois it reached only about halfway from the shore of Lake Michigan to Mississippi and Ohio rivers. As the ice drew back, each lake basin, at the time of most pronounced lobation, had its ice lobe, which conformed to the outlines of its southern part with remarkable fidelity. The moraines laid down along the margin of the lobes at this stage are roughly concentric with the basins and nearly parallel with their southern shores.

OSCILLATIONS OF THE ICE FRONT.

The periodic oscillations in the retreat of the Wisconsin ice sheet introduced a peculiar complexity into the lake history. It has been shown above that the stronger or principal moraines formed at the culmination of a readvance mark relatively long intervals of time—several hundreds of years, perhaps more than a thousand. The readvance to the moraine covered a very considerable distance, certainly in some cases 25 to 50 miles and perhaps twice as much. The long intervals of time between a moraine that precedes and one that follows such an oscillation accounts perhaps to some extent for the commonly observed discordant relation between them.

Important oscillatory variations in the retreat of the ice produced a corresponding effect on the lake history, for after lakes were lowered by a retreat of the ice the readvance was likely to close their outlets and raise their waters to higher levels. Three times, certainly, and perhaps four or five times such a change affected the waters of the Huron-Erie-Ontario basin. During several oscillations the ice front stood in critical relations to the land barriers that held up the lakes and relatively slight changes in position opened or closed outlets and changed the level of the lake waters.

In view of the apparent character of the glacial oscillations it seems necessary to take account also of the halts of the ice front at the back steps or climaxes of retreat. These probably affected the lakes as greatly and lasted as long as did the halts on the moraines which mark the climaxes of advance. In one place at least there is remarkably clear and complete proof of the long duration of a particular lake stage (Arkona) which existed during the pause at a back step or climax of retreat. The changes of the lakes during the retreat of the ice front across the Huron-Erie-Ontario basin are the most complicated now known and form the central theme of the discussion that follows.

THE FIRST LAKES.

As soon as the ice front withdrew to the north side of the southern watershed of the Great Lakes small ice-dammed lakes began to be formed. In Ohio a number of such lakes appeared along the north side of the divide south of Lake Erie. It seems a necessary inference that in consequence of the oscillations of the ice many of these earliest small lakes were formed at the extreme position of retreat and were overridden and obliterated by the next readvance. Indeed, some of them may have been formed and overwhelmed two or three times before the larger lakes became permanently established. There is some evidence of this sort of development at Fort Wayne, Ind.

The earliest small lakes discharged at first southward independently through several gaps in the divide; a little later they fell to lower levels and discharged westward to a lower gap; and finally they discharged into the first small, narrow representative of glacial Lake Maumee. Mr. Leverett has already described these earliest lakes in Ohio;[1] he has also described others of some-

[1] Leverett, Frank, Glacial formations and drainage features of the Erie and Ohio basins: Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 610-611.

what similar origin that were formed along the east side of the Lake Michigan basin (pp. 225–227). Winchell has described a series of small lakes that preceded the larger lakes in the western end of the Lake Superior basin.[1]

When the ice front had retreated to a position a little east of the watershed at Fort Wayne, Ind., a long, narrow, crescent-shaped lake, known as glacial Lake Maumee, was formed between the ice barrier and the land. Similarly, when the ice front had withdrawn a few miles north of the watershed at the south end of Lake Michigan and was building the later members of the Lake Border morainic system, another long, slender, crescent-shaped lake was formed between the ice barrier and the land; this was the beginning or first stage of glacial Lake Chicago. If the moraines have been rightly interpreted Lake Maumee came into existence shortly before Lake Chicago.

A third lake of the same kind (Lake Duluth) was formed in the same way at the western end of the Lake Superior basin, when the Lake Superior ice lobe finally shrank within the line of the watershed west of Duluth. Mr. Leverett's work in Minnesota in 1910 and 1911 indicates that the beginning of this lake was considerably later than that of the first lakes at Fort Wayne and Chicago. He makes a tentative correlation of the Port Huron morainic system (formed at the time of Lake Whittlesey) with a moraine which encircles the west end of Lake Superior and antedates Lake Duluth, thus making Lake Duluth younger than Lake Whittlesey.

Two small lakes, formed probably a little later than Lake Chicago, gathered in front of the Green Bay lobe of the ice sheet in Wisconsin and discharged first southward to Rock River and then southwestward to Wisconsin River. These lakes, however, had a relatively short independent existence, for they soon combined into one lake and when the retreating ice opened a passage eastward to the basin of Lake Michigan their waters merged with those of Lake Chicago.

From these four relatively small beginnings there grew a series of glacial lakes, the like of which for size and complicated history is not known in any other part of the world. The total area covered by their waters from first to last was much greater than the entire area of the present Great Lakes, but the whole area was not covered at any one time. Only one glacial lake of larger size is known to have existed; this is Lake Agassiz, which overspread northwestern Minnesota, northeastern North Dakota, and a great area in Manitoba and Saskatchewan. But the history of Lake Agassiz appears to have been very simple in comparison, for the basin which it occupied was simpler in form and its relations to the ice sheet were less complicated.

GLACIAL LAKES IN THE HURON-ERIE BASIN.

COMPLEXITIES OF DEVELOPMENT.

The lowland which stretches from Lake Huron southward to Lake Erie was abandoned by the ice sheet in the middle stages of the development of the glacial lakes, but continued to be covered by the lake waters, so that the waters in the southern part of the Lake Huron basin were joined with those in the basin of Lake Erie as one, and at a later stage this extensive lake was further expanded so as to cover the western part of the basin of Lake Ontario.

The succession of lakes in this basin is more complex than in any other part of the lake region. These complexities grew out of several different causes: (1) The configuration of the chief elements of relief—deeper basins separating higher lands and ridges, and the position and varying altitude of the watershed south of the lakes; (2) the general direction of the glacial retreat and the trend of the ice front with reference to these features; (3) the oscillations of the ice front during retreat, comprising not only periodic movements of retreat and halt, but also alternating movements of readvance over relatively wide intervals of space; and (4) (especially in the later stages) the tilting or northward differential elevation of the land. The readvances of the ice introduced the greatest element of complexity and produced their effects chiefly by closing outlets and raising the level of the waters. This occurred repeatedly shortly after the waters had been lowered by a movement of retreat.

[1] Winchell, N. H., Bull. Geol. Soc. America, vol. 12, 1900, pp. 121-122.

LAKE MAUMEE.

Lake Maumee had at least three distinct stages and possibly more. Those clearly determined are as follows:

Highest stage.—As the ice front retreated eastward from the moraine at Fort Wayne, Ind., it uncovered what is now the upper Maumee Valley, but continued to occupy the present lower part of that valley and therefore to obstruct its normal northeastward drainage. Consequently, Lake Maumee came into existence between the moraine and the ice front. As the ice retreated the lake widened eastward and long arms of water extended eastward into Ohio and northeastward into Michigan between the shrinking ice lobe and the land.

How far the ice retreated is not certain. The next strong moraine in the Maumee Valley is at Defiance, Ohio, but in view of the periodicity and the wide space covered by the readvances, it may be regarded as certain that the retreating ice front did not stop at Defiance but receded to a point probably not less than 25 or 30 miles east of that place and there halted for a considerable time before readvancing. There were also minor oscillations during both of these movements.

The waters of the lake rose until they found an outlet westward through the present site of Fort Wayne and thence southwestward to Wabash River at Huntington and ultimately to Ohio and Mississippi rivers and the Gulf of Mexico. The time of the opening of this outlet is not certain. Possibly the lake stood at its highest level and discharged at Fort Wayne during the climax of its retreat, although this is doubtful. But during its readvance to Defiance and its pause at the Defiance moraine it certainly overflowed at Fort Wayne. The first stage ended only when the Fort Wayne outlet was finally abandoned.

Lowest stage.—When the ice front retreated from the Defiance moraine it fell back a long step to the eastward and opened a lower outlet somewhere near Imlay, in Lapeer County, Mich. Below the highest or first beach of Lake Maumee there are two others which evidently belong to this lake. One, the middle beach of Lake Maumee, is 15 to 25 feet below the first beach and is a normal wave-made shore line of moderate strength. The other or lowest beach, which is about 20 feet below the middle beach, is faint and fragmentary and has been greatly modified by later submergence. These two lower beaches have a curious relation; the lowest beach was made next after the highest and then the level of the lake was raised and the middle beach was made at a higher level. The storm waves which made the middle beach swept over the gravelly ridges of the earlier one below, which lay in 20 feet of water, and almost destroyed them. Hence, when the lowest beach was being made the lake was in the second stage. The location of the outlet for this stage is not known with certainty; it may have passed northward a few miles east of Imlay and thence westward across Tuscola County, but if so it was overridden and obliterated by a readvance of the ice. In its horizontal part the lowest beach is 760 feet above sea level.

Middle stage.—When the ice front readvanced, it closed the outlet for the lowest stage and moved westward to a position close along the east side of the great Imlay outlet channel, which passes northward just east of Imlay. This channel shows evidence of having been crowded westward by the ice as it was building the moraine along its east side. At this stage Lake Maumee was barely too low to overflow at Fort Wayne.

When the ice retreated from this last position, it opened a temporary outlet across Tuscola County, but did not open a permanent new outlet until it had retreated many miles to the north toward the northern part of the "thumb." The opening then made, however, allowed the lake waters to fall suddenly to a much lower level.

In the middle or latest stage Lake Maumee reached its greatest extent, stretching from Fort Wayne, Ind., northward to a point several miles north of Imlay, Mich., and eastward nearly to Girard, Pa. The front of the contemporary ice lobes probably extended from the vicinity of Detroit into Lake Erie, 40 or 50 miles east of Toledo. At its front the ice was therefore standing in water 150 to 200 feet deep.

LAKE SAGINAW.

During the later stages of Lake Maumee a small lake appeared in the Saginaw Valley in front of the Saginaw ice lobe and received the drainage of the Imlay outlet river. At first it was narrow and crescent shaped, but it grew somewhat larger and wider before the end of Lake Maumee. Its outlet was westward through the Grand River channel for a few miles west of Grand Rapids and thence south along the ice front to Lake Chicago. Lake Saginaw was merged with Lake Arkona, restored to independence during Lake Whittlesey, and merged with Lake Warren before its final extinction by the abandonment of its outlet.

While it existed as an independent body, Lake Saginaw was limited to the Saginaw Valley, which is a part of the basin of Lake Huron. It was also a part of Lake Wayne and later of Lake Lundy, but the outlet was then eastward to the Mohawk near Syracuse, N. Y.

GLACIAL LAKES IN THE HURON-ERIE-ONTARIO BASIN.

LAKE ARKONA.[1]

The next important step in the ice retreat changed still more profoundly the condition of the glacial lakes. (See fig. 6, p. 370.) The ice withdrew altogether from the "thumb" of Michigan, allowing the entire sweep of lake waters to the eastward to fall to the level of Lake Saginaw and to merge with that lake. Lake Saginaw had at the same time expanded largely northeastward, and a strait several miles wide had opened past the end of the "thumb." The enlarged lake, which is called Lake Arkona, stretched from the vicinity of Gladwin, Mich., to at least 40 or 50 miles east of Buffalo, N. Y., and covered a considerable part of southern Ontario. Its outlet was westward through the Grand River channel. Its altitude above sea level was at first 710 feet, but by cutting down of the outlet it became reduced to 694 feet. West and northwest of Port Huron are three beach ridges formed by this lake, known as the Arkona beaches.

LAKE WHITTLESEY.

After the formation of the Arkona beaches the ice front made a pronounced readvance southward up the slope of the "thumb" to Ubly, building the Port Huron morainic system, cutting off the Saginaw Valley, and restoring Lake Saginaw to independence. The advance had no effect on the waters of Lake Saginaw, but it raised those of the lake area east of the "thumb" by about 44 feet, forming a new lake, known as Lake Whittlesey, whose surface stood about 28 feet above the highest Arkona beach ridge in the region northwest of Port Huron and 44 feet above the lowest.

On the northern part of the "thumb" the Arkona beaches were overridden by the ice and a considerable extent of them was buried beneath the terminal moraine or beneath outwash. In the southern part of the Black River valley northwest of Port Huron they were not overridden nor buried but were submerged. Within the valley they are strongly developed gravelly beach ridges and show no modification due to submergence. Outside, on the south, however, they were almost entirely washed away by the storm waves of Lake Whittlesey and in many places are traceable only with much difficulty. Although they were 28 to 44 feet under the water, the storm waves swept their gravels rapidly up the slope and built them into the Whittlesey beach.

The Whittlesey beach has characters which indicate that it was pushed up the slope as it was made and that it was made rapidly, for it stands very high above the adjacent land and is peculiarly independent of topography, crossing valleys of moderate depth in a direct line like a railroad embankment.

LAKE WAYNE.

Below the Arkona beaches lies the Warren beach and next lower the Wayne beach. But the Wayne, like the Arkona and middle Maumee beaches, shows evidence of having been submerged and modified while the Warren beach was being formed above it at the margin of the raised lake. The lake level appears to have dropped abruptly 80 or 85 feet from the Whittlesey beach

[1] The lakes preceding Lake Arkona were confined to the Huron-Erie basin and did not include any part of the basin of Lake Ontario. Lake Whittlesey, following Lake Arkona, was also limited to the Huron-Erie basin.

to the Wayne beach, the drop being of course due to a recession in the border of the ice, which permitted the reunion of Lake Saginaw with the larger lake to the east and caused a further lowering of these united waters by about 40 feet.

The Wayne beach is generally faint, and on the "thumb," where it is gravelly, it shows distinct evidence of submergence and modification after it was made. Except on the "thumb," it is generally sandy and without marked characteristics. In the Saginaw Valley it lies barely below the head of the channel which had served as the outlet of Lake Saginaw. It is quite certain that it had no outlet toward the northwest through the Straits of Mackinac, and it probably drained eastward to the Mohawk, passing along the ice margin, where it rested on the hills south of Syracuse, N. Y.

LAKE WARREN.

When the ice front readvanced, covering part of the ground previously vacated, it closed the outlet which had recently been opened near Syracuse and raised the lake to the level of the Warren beach. In the Saginaw Valley the Warren beach passes 20 to 25 feet above the col at the head of the Grand River outlet channel, here extremely flat and much covered with dunes.

In Michigan the Warren beach extends up to the vicinity of Au Sable River north of Saginaw Bay but has not been identified farther. In New York it has been traced for some distance east of Genesee River. Its limits in Ontario have not been determined. While the Warren beach was being made the Wayne beach was being destroyed, and the Warren beach, like the Whittlesey, shows in some places but not so strongly the characters which indicate rapid accumulation.

In the later stages of the lake waters, from Lake Arkona on, the area covered by the lakes included not only the basin of Lake Erie but parts of those of Lakes Huron and Ontario also. From New York, Fairchild reports evidences of a readvance and raising of lake level later than the one which affected Lake Warren. That movement, however, appears to have been confined to the Lake Ontario basin and had no effect upon the waters of the Huron-Erie basin.

The beaches of all the foregoing lakes are horizontal in the southern part of the region they cover, but in the northern part they rise slightly toward the north-northeast. The area of horizontality lies southwest of a line passing about 5 miles north of Birmingham, Mich., to Ashtabula, Ohio. This seems to have been a sort of hinge line for the earlier deforming movements. North of it all the beaches rise gradually in a direction about north-northeast, but the earlier ones begin to rise before the later ones, as if the deforming force had migrated slowly northward, following the retreat of the ice front.

LAKE LUNDY (LAKE DANA, LAKE ELKTON).

When the waters fell from Lake Warren they halted first at the Grassmere beach and later at the Lundy (Dana, Elkton) beach, before they finally separated from the waters of the Lake Erie basin. The outlet at both stages was probably near Syracuse, N. Y., but connection with that region has not been established by continuous tracing. It was probably during the time of Lake Lundy and perhaps also during that of Lake Wayne that the great cataracts (allied to Niagara) existed in the hills southeast of Syracuse, N. Y.

The two beaches have only moderate strength. On the "thumb" they show the most remarkable example of northward splitting that has been found. The outer part of the "thumb" was being elevated while they were being made, and each beach consequently splits from a single strand to four or five separate weaker strands covering a vertical interval of 25 to 30 feet. In the area of horizontality the Grassmere has an altitude of 640 feet and the Lundy (Dana, Elkton) of about 620 feet. Both are generally gravelly on the "thumb" but are sandy elsewhere. They have been studied very little east of Michigan, probably in part because they are weak. They mark the transition to Lake Algonquin, the largest of the glacial lakes in the Great Lakes region.

GLACIAL LAKES IN THE LAKE ONTARIO BASIN.

EARLY LAKES.

When the Lake Ontario ice lobe had retreated far enough to uncover the southern parts of the valleys of the Finger Lakes in central New York, small lakes gathered, at first as separate bodies. With continued recession these lakes were lowered and combined in a complex series of changes that led finally to the later, larger lake that filled the whole basin of Lake Ontario. These changes have been set forth in considerable detail and illustrated by a series of maps by Fairchild.[1] The first local glacial lakes had independent outlets toward the south. The succession of lakes, as given by Fairchild, is as follows: Watkins, Newberry, Hall, Vanuxem, Second Vanuxem, Warren, Dana, Dawson, Iroquois.

LAKE NEWBERRY.

The first combination of the dozen or more small lakes in the Finger Lakes valleys into one lake has been called Lake Newberry. Its outlet was southward from Seneca Lake to Susquehanna River.

LAKE HALL.

At a slightly later stage of recession an outlet was opened westward to the glacial waters in the Lake Erie basin. The lake at this stage is known as Lake Hall.

LAKE VANUXEM.

At a slightly later stage a lower outlet was opened eastward to the Mohawk Valley, and this stage is known as Lake Vanuxem. After this there was for a time free drainage eastward, with only two low, small lakes, one in the Genesee Valley and one in the valley of Cayuga Lake. Later, however, on the readvance of the ice front, Lake Vanuxem was reestablished (Second Lake Vanuxem), after which the waters of the southern part of the Lake Ontario basin again merged with those in the Huron-Erie-Ontario basin.

LAKE DAWSON.

When the waters had fallen so as to separate those in Lake Erie from those of the Lake Ontario basin, an outlet was established eastward past Syracuse, N. Y. A number of oscillations of lake level, corresponding to slight retreats and readvances of the ice front, probably occurred. Toward the end of these oscillations the ice front, according to Fairchild, rested against the relatively high ground east of Rochester, forming a barrier across the Lake Ontario basin and dividing the waters into two bodies, Lake Dawson on the west and a smaller lake, draining from Lake Dawson and emptying into the Mohawk, on the east.

LAKE IROQUOIS.

When the waters of the Lake Ontario basin fell to the level of the pass at Rome, N. Y., they discharged eastward through the Mohawk Valley. This established Lake Iroquois, which endured for a relatively long time. The land, however, was uplifted around the north and east sides of this basin while the lake was discharging at Rome. This backed the water up on the south and west and caused it to fall away from the northern and eastern shores.

LAKE FRONTENAC.

When the retreating ice opened a passage eastward around the north side of the Adirondack Mountains to the basin of Lake Champlain, the lake level fell and the outlet at Rome was abandoned. At this stage the ice barrier or dam rested about on the Frontenac axis of the pre-Cambrian rocks and the lake may therefore be called Lake Frontenac.

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[1] Fairchild, H. L., Glacial waters in central New York: Bull. New York State Mus. No. 127, 1909.

GILBERT GULF.

Finally the sea, which then stood relatively higher than now (523 feet higher near Covey Hill on the northern base of the Adirondacks),[1] entered and turned what had been a glacial lake into a marine gulf, known as Gilbert Gulf.

GLACIAL LAKES IN THE LAKE MICHIGAN BASIN.

LAKE CHICAGO.

While this complicated history was being enacted in the Huron-Erie-Ontario area, the glacial waters in the basin of Lake Michigan were also undergoing expansion. Here, however, the changes were extremely simple, for until the very last no critical ground affording a new outlet was encountered. The changes that occurred in Lake Chicago were due to erosion of its outlet or to changes in the volume of its discharge. From its first beginning as a narrow crescent-shaped lake at the extreme southern end of the Lake Michigan basin Lake Chicago had expanded northward as the ice receded until two-thirds or three-fourths of the basin was uncovered. In all probability the retreating ice front performed here the same series of oscillations, with strongly marked steps of retreat and readvance, that took place in the Huron-Erie basin. The evidence of these oscillations, however, are not generally so well marked, because critical changes were not produced by them; but some of the stronger moraines mark readvances that override beach ridges which had been made just previously.

The Port Huron morainic system skirts the north side of the high ground of the southern peninsula of Michigan and appears to be correlated in part with the morainic ridges which pass beneath Lake Michigan just south of Manistee. The Whitehall moraine of the Lake Michigan basin is considered to be a part of the complex Port Huron morainic system.

Studies by Alden,[2] under the direction of Chamberlin, on the west side of the Michigan basin, have developed evidence of a distinct readvance of the ice to Milwaukee characterized by a deposit of red till, and this probably correlates with the Whitehall moraine (p. 302). Later ridges of red till, which come down to the shore of Lake Michigan near Manitowoc and Two Rivers, Wis., also probably correlate with the Manistee moraine. This correlation is inferred not only because of similar position on opposite sides of the lobe and in reference to earlier moraines, but also because these later ridges do not appear to carry the Calumet and Glenwood beaches of Lake Chicago (see pp. 354, 355), which are present on the Whitehall moraine. Two lower beaches in the same area seem to have wider connections. The upper one is the Toleston beach, 24 or 25 feet above Lake Michigan, and the Nipissing beach, about 15 feet above the lake. The summit in the Chicago outlet in the south part of the city is only 8 feet above Lake Michigan, and is a broad, flat region much obstructed by low, sandy ridges. The Toleston beach passes over this broad divide at a level high enough to have permitted Lake Chicago to discharge over it, even when it received the discharge of Lake Whittlesey or Lake Warren. Nevertheless, the Toleston beach seems to be continuous with the Algonquin beach, which traverses all of the upper three lake basins, and part of the overflow of Lake Algonquin may have been by way of Chicago for a time. The relation of the Chicago outlet to Lake Algonquin is still somewhat problematic.

When the ice lobe in the Lake Michigan basin retreated into the northern part of that basin it uncovered ground of critical interest on both sides. On the west side the glacial waters of the Lake Superior basin had been held up to a higher level than those of Lake Chicago, and when an opening occurred around the hills southeast of Marquette these waters drained southward along the western edge of the Green Bay lobe of the ice sheet and ultimately into Lake Chicago.

Bordering the west shore of Lake Michigan and extending into the Green Bay-Lake Winnebago trough and the Fox and Wolf river valleys is an extensive deposit of red clay, partly

[1] Fairchild and Goldthwait, personal communications.

[2] Alden, W. C., personal communication.

laminated and partly pebbly and massive, which was described by Chamberlin.[1] Later study of this deposit by Alden,[2] under the direction of Chamberlin, shows that the larger part of this deposit, the massive pebbly clay, is a glacial till which was laid down during a readvance of the glacier in the Lake Michigan basin as far south as Milwaukee and of the Green Bay lobe in the Green Bay-Lake Winnebago trough to a point south of Fond du Lac, Wis. The ice also crowded westward in the Fox and Wolf river valleys. The red silt composing the laminated clay and the matrix of the massive pebbly clay is thought to have come from the Lake Superior region, being brought into the Green Bay and Lake Michigan basins by the opening of a southward outlet southeast of Marquette. The first opening of this outlet must have been at or near the climax of the ice retreat, immediately before the readvance to the first red till moraine. The phenomena indicate a readvance over a relatively wide interval, and it seems certain that if a lower outlet had been opened by the retreat it was closed again by the readvance, and that the level of the glacial waters in the western half of the Lake Superior basin was raised again to the level of some earlier and higher outlet. In fact, Mr. Leverett's studies have led him to the tentative interpretation that at the time of this readvance the ice completely occupied the western Superior basin, so that all the beaches of Lake Duluth are later.

On the east side, the retreating ice front finally reached the straits of Mackinac, where an opening allowed the waters of Lake Chicago to unite with those of the Lake Huron basin. Whether this merging of the waters in the Lake Michigan and Lake Huron basins occurred before or after the opening of the Trent Valley outlet in Ontario is not certainly known.

LAKES IN THE GREEN BAY BASIN.

Very little has been written concerning the glacial lakes in the Green Bay basin, and their extent has been as yet only partly worked out. Upham [3] published a paper in 1903 suggesting Jean Nicolet as the name for a lake that discharged from the Fox River drainage past Portage, Wis., to the Wisconsin Valley. Upham's paper was based on a brief visit to the outlet, and the existence of the lake was inferred partly from the presence of the outlet channel and partly from Chamberlin's description of the red clays in the Green Bay basin as lacustrine.[4] Alden's studies [2] have shown that the red clay was largely worked over and formed into morainal ridges and till sheets by a readvance of the ice, so that the limits of the red clay in the Green Bay basin mark a glacial instead of a lake border. Alden's studies have also shown that the lake history in this basin is somewhat different from that set forth by Upham. A lake, which discharged from the district south of Lake Winnebago southward past Horicon into Rock River, persisted until the ice which formed the moraines at the head of Lake Winnebago had receded far enough northward to open a passage westward from Oshkosh to the headwater part of Fox River. Then the discharge was shifted past Portage to the Wisconsin Valley. Later, when the melting of the ice cleared the Green Bay peninsula, the waters lowered to the Lake Winnebago level and to a lake in the Green Bay basin by discharging eastward into Lake Chicago. Similar events accompanied the preceding recession of the ice front and also, in reverse order, the readvance of the ice which formed the red till moraines.

GLACIAL LAKES IN THE LAKE SUPERIOR BASIN.

EARLY LAKES.

From the first small lakes at the extreme western end of the Lake Superior basin the glacial waters expanded as they did in the Lake Erie and Lake Michigan basins. In the earlier stages, while the lakes were small, slight changes in outlet and level occurred, the early stages having southward outlets directly or indirectly to the St. Croix Valley.

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[1] Geology of Wisconsin, vol. 2, 1877, pp. 221-228.
[2] Alden, W. C., personal communication.
[3] Am. Geologist, vol. 32, 1903, pp. 105-115, 330-331.
[4] Geology of Wisconsin, vol. 2, 1877, pp. 221-228; Geologic Atlas of Wisconsin, Pl. II, 1881.

LAKE DULUTH.

Finally came Lake Duluth, with its outlet southward through the Brule and St. Croix valleys. Lake Duluth endured for a much longer time than the earlier lakes and its lower levels expanded to a lake of large size, forming beaches found even on the northern part of the Keweenaw Peninsula. Its outlet was cut down about 40 feet, lowering the level of the lake and causing the formation of later beaches below the highest.

Several lower beaches, which have been traced by Mr. Leverett (p. 431), seem to lie too low for waters discharging through the St. Croix outlet and hence may not belong to Lake Duluth. These suggest an outlet somewhere to the east and south around the hills south of Marquette, the exact place being not yet determined. These beaches are rather weak and suggest the possibility of submergence in consequence of a readvance of the ice.

GLACIAL LAKES IN THE SUPERIOR-MICHIGAN-HURON BASIN.

LAKE ALGONQUIN.

Stages of Lake Algonquin.—In the outline given above the succession of lakes in each of the upper three basins—those of Lakes Huron, Michigan, and Superior—were given down to the time when the glacial waters in all three were about to merge into one great lake. This larger body is called Lake Algonquin and its upper beach is one of the strongest and most persistent shore lines in the Great Lakes region. At its greatest extent this lake covered an area considerably larger than all three of the upper Great Lakes of the present time.

When the lake waters fell to lower levels from Lake Warren and Lake Lundy they uncovered for the first time the lowlands between Lakes Huron and Erie. This lowland divided the waters into two separate lakes and inaugurated the flow of St. Clair and Detroit rivers.

Lake Algonquin may be divided into four stages: (1) Early Lake Algonquin, confined to the south part of the Lake Huron basin; outlet at Port Huron. (2) Kirkfield stage, covered all of the upper lakes except the northern part of Georgian Bay and probably the northeastern part of Lake Superior; outlet at Kirkfield, Ontario; uplift in north begins. (3) Port Huron-Chicago stage; outlets at Chicago and Port Huron, but diminishing at Chicago and increasing at Port Huron; great uplifting, producing divergence of beaches northward; three groups of beaches, Upper Algonquin, Battlefield, and Fort Brady; most rapid uplift during Battlefield group. (4) Closing transition stage leading to Nipissing Great Lakes; outlet eastward to the Ottawa Valley.

Early Lake Algonquin.—For a relatively brief stage immediately following the time of Lake Lundy the waters in the south half of the Lake Huron basin formed an independent lake. This has been called Early Lake Algonquin. It was at the beginning of this stage that St. Clair and Detroit rivers first came into existence, and the outlet during this time was through these rivers to Lake Erie. The ice front then rested against the highlands which bounded the two sides of the southern half of Lake Huron, as shown by the moraines in both Michigan and Ontario. This stage, however, was relatively short, for the ice front stood so far north at its beginning that a slight additional retreat opened passages to the east and northwest where lower outlets were available—to the east to Georgian Bay and Trent Valley in Ontario and to the northwest to Lake Chicago. These two passages probably opened nearly at the same time. From the fact that no separate beach or outlet is known for this stage it might be thought that it is wholly hypothetical and its existence entirely uncertain. But, besides the local consequences of the relation of the ice sheet to the highlands, the early distributaries of the St. Clair and Detroit rivers seem inexplicable except as incidents of the transition from Lake Lundy to a lower stage with southward outlet corresponding to Early Lake Algonquin. And, further, the five short gorges made by Niagara River in the Niagara escarpment during its early flow show conclusively that the river then had a volume as large or perhaps larger than at present, and this it could not have had unless it received a large contribution of water to Lake Erie from the north. This was clearly before the opening of the Kirkfield outlet in Ontario. The discharge from Early Lake Algonquin was larger than might be expected, because

this lake received a large affluent from the east, from the region of the Nottawasaga Valley and Lake Simcoe in Ontario, and also a large amount directly from the ice barrier.[1]

Kirkfield stage.—There is no reason to suppose that the Chicago outlet was at first low enough to take the whole discharge from Port Huron. On the other hand, the Trent Valley outlet at Kirkfield, Ontario, was surely low enough, and as soon as a way was opened to it the overflow went there and the level of the lake fell below the outlets at Port Huron and Chicago, for the character of the outlet channel at Kirkfield and below shows that it carried the full discharge of the upper lakes for a long time. Indeed, the principal or upper strand of the Algonquin group of beaches is remarkably strong and continuous not only in the southern parts of the basins but runs on unbroken in the same character far toward their northern sides. If it is lacking anywhere it can be only on the far northern sides of the basins, for it is strongly developed on the high ground north of Sault Ste. Marie, Ontario. Apparently during the making of the upper strand the lake was nowhere subject to deforming or warping influences and the outlet was at Kirkfield.

At length when the ice sheet had almost entirely disappeared from the lake basins a great movement of differential elevation began to affect the land. This movement embraced a vastly greater area than that of the Great Lakes, but within this area it affected the northern parts most. South of a line running through the middle of the "thumb" of Michigan and across the south arm of Lake Huron about S. 68° E. and also south of a line running westward across Lake Michigan from a point south of Frankfort the Algonquin beach was not affected at all by the uplift. This line was a sort of "hinge" line for the movement. Kirkfield at the head of the Trent Valley outlet was well within the region of strong uplifting, so that probably early in the movement it was raised to a position higher than the outlets at Port Huron and Chicago. The Kirkfield outlet was then abandoned and the discharge was shifted to Port Huron and Chicago. South of the isobase of Kirkfield the Algonquin beach of to-day is not the first beach made when the Kirkfield outlet carried the whole discharge, but is a transition beach made when two or probably three outlets were active at once. This might be called the Algonquin transition or three-outlet beach, but the name Algonquin beach has generally been applied to the whole strand. The original Algonquin beach is now seen only in the region north of the Kirkfield isobase. While the Kirkfield outlet was active and carried the whole discharge, the isobase of that outlet served as a nodal line on which the water plane swung, the shores to the north of it being left dry and those to the south of it drowned.

In the region north of the hinge line uplifting and tilting progressed with increasing rapidity. The outlet at Kirkfield was raised altogether something more than 270 feet after its abandonment, for it now stands 295 feet above the level of Georgian Bay, and Lake Huron in the meantime has been lowered 25 feet by the erosion of its outlet at Port Huron. Farther north and northeast the amount of elevation was still greater.

Northward from the hinge line the beach for some distance rises gradually, but about on an isobase passing through Traverse City it begins to rise more rapidly and begins also to split into a vertically diverging series of subsidiary strands which are separated by wider and wider vertical intervals toward the north. This splitting of the strands toward the north shows that the land was being differentially elevated during the life of the lake. The different strands are not of the same strength nor are they equally spaced vertically, showing apparently that the uplifting movement was not steady in its progress, but was marked by a number of longer or shorter pauses.

The split-up strands seem to fall naturally into three groups, the upper group keeping close parallelism for the farthest distance north and apparently recording relatively slow movement in the beginning of the uplift. They probably record also some lowering of the lake by downward cutting at the outlet, but the amount was certainly small. In the Lake Superior basin the

[1] If the plan of naming the lake stages were strictly adhered to a separate name would be applied to this stage and the name Algonquin would not be used. This stage should be put under the head of "Glacial lakes in the Huron basin." But partly because there was at first a lack of complete proof of the existence of this stage and partly because the multiplication of names for lake stages seemed undesirable, the name Early Lake Algonquin was used and it has now appeared so many times in printed texts and on published maps that it seems impracticable to make a change.

northern limits of the upper Algonquin beach have not yet been satisfactorily determined, and the amount and differential effects of the elevation there are not accurately known.

The middle group of Algonquin beaches comprises the Battlefield beach of Mackinac Island and two or three fainter strands not far below it. These, like those above them, converge to the hinge line.

The third group comprises the Fort Brady beaches, generally several in number and of moderate strength. These beaches lie close above the Nipissing beach and appear to converge with the other beaches to the hinge line.

The Kirkfield outlet was closed rather late in the life of Lake Algonquin. The idea held formerly that the postglacial uplifts of the land in the Great Lakes region were gradual and that they were evenly distributed through time is an error. The uplifting movements were evidently spasmodic, relatively sudden, and rapid. Almost all the deformation has occurred since the later part of the life of Lake Algonquin.

Port Huron-Chicago stage.—When the Kirkfield outlet was abandoned it seems probable that the overflow went first in greater part to Chicago, leaving only a relatively small part to flow south at Port Huron. But the Chicago outlet rested on a rock sill and held firm, and the Port Huron outlet deepened with relative rapidity, so that before long the lake level had fallen 10 feet and the Port Huron outlet had taken almost all the overflow away from Chicago. The Toleston Beach was formed at the time of this large-volume discharge at Chicago; any earlier beach of Lake Chicago controlled by the same sill must have been overwhelmed and worked over entirely by the Algonquin. On this hypothesis Toleston is in reality only a local name for the part of the Algonquin beach developed in the southern part of the Lake Michigan basin.

From the fact that the Kirkfield outlet appears to have carried the whole discharge of the upper three lake basins and that it was uplifted and abandoned rather late in the life of Lake Algonquin, the conclusion follows that while this outlet was active, the Chicago and Port Huron outlets were both left dry. This means that during this time the shores of Lake Algonquin throughout all the region south of the isobase of Kirkfield stood at a level at least a little below these two abandoned outlets. Hence, the upper Algonquin beach south of the isobase of Kirkfield was not made during the principal activity of that outlet, but during the Algonquin transition stage of the lake, when a considerable part of the overflow had left Kirkfield and gone to Chicago and Port Huron. The upper Algonquin beach was therefore a transition beach, made principally during the gradual lowering of the lake for 10 feet or more while the overflow was at Chicago and at Port Huron, with Port Huron gradually cutting down and gaining in volume. The character of the Algonquin beach agrees remarkably well with this conception of Lake Algonquin's history.

It was during the third or Port Huron-Chicago stage of Lake Algonquin that the larger part of the remarkable uplift of the Great Lakes region occurred. It began when the Kirkfield outlet was active, but soon raised Kirkfield higher than Port Huron and Chicago and shifted the outflow to these two places. The great uplift caused a remarkable northward splitting and divergence of the beaches blow the highest Algonquin. As a consequence the beaches of this stage are many in number and show a large vertical divergence northward. They seem to fall readily into three groups, the upper or main Algonquin, the Battlefield, and the Fort Brady. The main uplift began during the second or Kirkfield stage, but much the greater part occurred during the third or Port Huron-Chicago stage, and the most rapid upward movement was during the making of the Battlefield group of beaches. At Sault Ste. Marie the vertical interval between the highest Algonquin and the Nipissing beaches is 365 feet, whereas in the area of horizontality (at Port Huron and Chicago) the interval between these same beaches is 10 or 12 feet.

Transitional stage.—At its very end Lake Algonquin appears to have been held up by a relatively small glacial barrier at some point in the Ottawa Valley east of Mattawa. When this last dam broke out or shrank back northward the waters rushed eastward from Lake Algonquin through the Mattawa Valley to temporary glacial lakes in the Ottawa, Petawawa, and Madawaska valleys, and thence to the Champlain Sea, and came to a settled level in the upper lake basins only when the eastward-flowing outlet had been established on the col at North Bay.

The relation in time of Lakes Algonquin and Iroquois is a matter of great importance in connection with the study of the deformation of the land. Certain facts seem to show that Lake Iroquois had already been established when the Kirkfield outlet was opened. The scoured bed of the outlet river of Lake Algonquin, called by Spencer Algonquin River, is strongly marked between the small lakes of the Trent Valley. At Peterboro an expanded part of it, which stood so near the level of Lake Iroquois that it may have been a land-locked bay of that lake, is filled with a great deposit of gravel and sand. This appears to be a delta deposit of Algonquin River and seems to show conclusively that this river emptied into Lake Iroquois. But the facts now available seem to show that Lake Algonquin existed also for some time after Lake Iroquois had fallen, for the scoured bed of Algonquin River appears to extend down to the Bay of Quinte at Trenton, and in all probability reaches below the present level of Lake Ontario. It even passes below the probable level of the marine waters that entered the Lake Ontario basin. But below Peterboro it seemed to the writer to show less scour than above and in some places seems to suggest a smaller stream. At present the relation of this lower part to the lake history is quite problematic, for no other fact indicating so low a level for the waters of the Lake Ontario basin at that stage is known. It may be that while Algonquin River was still flowing the ice front withdrew far enough to allow Lake Iroquois to be drained off for a brief time, and then readvanced, restoring the lake for another relatively long period.

POSTGLACIAL HISTORY OF THE GREAT LAKES REGION.

POSTGLACIAL LAKES.

NIPISSING GREAT LAKES.

With the establishment of the outlet of the upper three lakes at North Bay a new order of things began. The ice sheet had disappeared from the Great Lakes region and no longer served as a dam or retaining barrier for any of its waters. This event may be taken as the place of division between the Pleistocene and Recent epochs of geologic time; the lakes (with their deposits) before this time belonging to the Pleistocene, those after it to the Recent.

At the beginning of this stage the Port Huron outlet had been abandoned. The new lake level, with its outlet at North Bay, lay in a plane which passed a little, though perhaps only a little, below the outlets at Port Huron and Chicago. During the later differential uplifting of the land, which occurred while the North Bay outlet alone was active, the isobase passing through that outlet became a nodal line on which the water plane swung. As elevation progressed the strands to the north of this line were abandoned and left dry, and those to the south were progressively submerged by the backing up of the water.

This order of changes continued until the North Bay outlet was raised as high as that at Port Huron. Then both outlets became active with the discharge divided between them. The beach made at this two-outlet stage has been called the Nipissing beach. In a strict sense, however, it is not the original Nipissing beach, made when the North Bay outlet alone was active, but a transitional beach made during the two-outlet stage. It might be called the Nipissing transition or two-outlet beach. The original Nipissing beach may be seen now only in the small part of the Lake Superior basin that lies north of the North Bay isobase or nodal line. This area, however, is so small and so close to the nodal line that the measurements thus far made have not yet disclosed any difference in the attitude of the old water plane on the two sides of the line. Theoretically there should be some difference and there probably is. South of the line the visible beach is the Nipissing transition or two-outlet beach, the original beach being everywhere submerged. But as no measureable change of plane has been found in crossing the nodal line the name Nipissing beach has generally been applied to the whole extent of the two-outlet strand.

The Nipissing beach thus defined has been traced with substantial continuity around all three of the upper lake basins and is, especially in the northern part of the area, much the strongest abandoned beach of the Great Lakes region. Its plane extends with almost perfect uniformity and with no certainly discoverable warping over all the northern parts of the basins.

Except in the basin of Lake Superior, the uplift which afterward tilted this beach appears to have hinged about on the same line as the earlier uplifts which raised the Algonquin beaches; in the Lake Superior basin it lies some distance north of the Algonquin hinge line. South of this hinge line the Nipissing beach is horizontal at about 15 feet above present lake level. North of it the beach rises at the rate of about 7 inches to the mile in a direction about N. 22° E. The Nipissing beach is now about 117 feet above Lake Huron at North Bay, about 70 feet above at Sault Ste. Marie, 48 or 50 feet above at Mackinac Island, and about 130 feet above (110 feet above Lake Superior) at Peninsula Harbor, near the northeast angle of Lake Superior.

The Nipissing beach shows remarkably strong development and maturity in all the northern parts of the basins, especially near the nodal line. For 150 miles or more south of the nodal line it is very strong, but farther south it seems gradually to diminish in strength, until in the area of horizontality it is little if any stronger than the Algonquin beach.

At the western end of Lake Superior the Nipissing beach appears to pass a little under the present lake level, a relation which probably accounts for the drowned condition of the shores and stream mouths of that region.

During the Kirkfield stage of Lake Algonquin the Port Huron outlet and St. Clair and Detroit rivers were abandoned and left dry, and they were abandoned in the same way during the time of the Nipissing Great Lakes. At both times Niagara River was robbed of the overflow of the upper three lakes, which amounted to 85 per cent of its volume.[1]

The Nipissing Great Lakes came to an end when the northern uplift raised North Bay enough to close that outlet and shift the whole discharge back to Port Huron. With this change the modern Great Lakes have their beginning.

POST-NIPISSING GREAT LAKES.

After the overflow came back to Port Huron the northern uplifting continued, though apparently more slowly, there being a series of fainter beaches on the slope below the Nipissing beach. One beach, especially, is slightly stronger than the rest and seems to mark a pause in the uplifting movement. This beach is called the Algoma beach because of its development at Algoma Mills, Ontario, where it lies about 50 feet above Lake Huron and 35 feet below the Nipissing beach. The Algoma beach has been found at many places farther south in a position a little more than halfway up from the present shore to the Nipissing beach.

On the north shore of Lake Superior a beach of moderate strength, standing in about the same relation below the Nipissing, was at first thought to be a beach belonging to the Lake Superior basin alone and determined by the outlet of that lake at Sault Ste. Marie. It was called the Sault beach[2] and was thought to swing on the isobase of that place as on a nodal line. It is believed to be submerged on the south shore of Lake Superior and around the west end. The Algoma beach appears to be due to a pause in the uplifting movement. In all probability there is a beach corresponding to the original description of the Sault beach, but it has not been certainly identified.

LAKE ERIE.

After Lake Erie became separated from Lake Ontario it ceased to be a glacial lake and from that time on was entirely independent of the ice sheet. By the time the separation had been accomplished following the fall of Lake Lundy, the basin of Lake Erie had probably been brought nearly to its present attitude. Since its separation it has had two low stages, while the Kirkfield and North Bay outlets were active, during which it was not receiving the discharge of the upper lakes. The Fort Erie beach, declining gently westward along its north shore from Fort Erie, Ontario, where it is 15 feet above the lake, is, at least at its east end, the correlative of the beaches of Early Lake Algonquin and of the Port Huron-Chicago stage of the greater Lake Algonquin. The two low-stage beaches made in the basin of Lake Erie during the Kirkfield stage of Lake Algonquin and during the Nipissing Great Lakes lay very nearly in the same plane, and both are now everywhere submerged.

[1] Taylor, F. B., Niagara folio (No. 190), Geol. Atlas U. S., U. S. Geol. Survey, 1913, pp. 21–22.
[2] Taylor, F. B., The second Lake Algonquin: Am. Geologist, vol. 25, March, 1905, pp. 166–167.

PRESENT STABILITY OF THE LAND.

In the northern part of the upper lakes many evidences, such as the newness of the modern shore line and of the mouths or lower courses of the Nipigon and other northern rivers, strongly suggest very recent or progressive emergence. In other parts of the lake region the evidence seems to be against progressive change. Gilbert found what he believed to be evidence of progressive change in the records of the lake gages, and he estimated the rate of differential uplifting. Recent investigations, however, have made changes in the data which he used and have necessitated a modification of his results.

Since the discharge returned to Port Huron, St. Clair River has cut down its bed by about 15 feet and Detroit River by half as much. This has greatly reduced the drowning of tributaries caused by the return of the full volume to Port Huron after the abandonment of that outlet during the time of the Nipissing Great Lakes.

In the western parts of the Lake Erie and Lake Ontario basins recent raising of the water level is indicated by drowned stream courses and in the Lake Erie basin by submerged stumps and creek beds described by Moseley as occurring in Sandusky Bay. These facts seemed at first to suggest that the tilting might still be in progress. But the drowning effects in these two basins, at least to depths of 10 or 15 feet, are probably due to the return of the large volume of discharge to Buffalo after the relatively long period of small discharge during the time of the Nipissing Great Lakes rather than to very recent or progressive tilting of the land. Both at Buffalo and on the St. Lawrence the outlet is on a rock sill and the downward cutting has been slight.

POSTGLACIAL MARINE WATERS IN THE OTTAWA AND ST. LAWRENCE VALLEYS AND IN THE LAKE ONTARIO BASIN.

When the ice sheet withdrew from the basin of Lake Ontario and the northern slope of the Adirondacks, the sea entered in its place and covered a large area. Its approximate limits are indicated by clays, gravels, and sands, which contain fossil remains of marine organisms such as are now living in the Gulf of St. Lawrence. The upper limit of the marine waters was about 350 feet at Plattsburg, N. Y., and 523 feet at Covey Hill, Ontario. It was at least 460 feet at Welsh's siding near Smiths Falls, Ontario, and may have been much more, for at the last-mentioned place the remains of a whale have been found in a gravel bed, definitely fixing a minimum upper limit of marine submergence. The height of marine submergence at Montreal is reported to be about 625 feet. On the south side of St. Lawrence River a well-defined beach marks what is taken to be the upper limit of the marine waters and has been called by Gilbert the Oswego beach. It declines gradually toward the southwest and passes under the present level of Lake Ontario about at Oswego.

The marine waters appear to have entered the basin of Lake Ontario some time in the later part of the time of Lake Algonquin. Uplift appears to have been in progress when the sea entered and to have soon ended the marine connection by raising the outlet above the sea. At the end of Lake Algonquin the sea probably did not extend above Cornwall and Ottawa.

CHAPTER XIII.

GLACIAL LAKE MAUMEE.

By Frank B. Taylor.

EARLY INVESTIGATIONS.

Glacial Lake Maumee has been discussed by Mr. Leverett,[1] who described the Fort Wayne outlet and the highest and middle beaches in considerable detail and briefly discussed the deformation of the beaches and the general relations of the lake to the ice sheet. Later[2] he described the shores of the lake in Wayne, Washtenaw, and Lenawee counties. Still later, in preparation for this monograph, Mr. Leverett and the writer made further studies in Lapeer, Macomb, and Oakland counties, especially with regard to the beaches and to the relations of the moraines of that region to the beaches and to the Imlay outlet. (See Pl. XIV.)

Since Mr. Leverett's earlier work was done the greater part of northern Ohio has been surveyed and mapped by the United States Geological Survey, making possible more accurate determinations of altitude on all the beaches and furnishing better foundation for studies of their deformation. Discrimination and correlation of the beaches of different parts of the area are also facilitated by these maps. Some helpful results have been obtained by putting the results of earlier work upon the new maps and studying them in the light of the later, more accurate altitudes. In this way it has been possible to correct some important errors due to aneroid barometer and to inaccurate railroad levels.

DISTRIBUTION OF MAUMEE BEACHES.

The highest and middle beaches of Lake Maumee are fully described by Mr. Leverett,[3] and it is not necessary to add to his general description. There is, however, a stretch in Ohio between Delphos and Findlay in which, since 1907, the writer has made some detailed studies of them with the aid of the topographic maps and has found some unusual features and some interesting data bearing on the attraction of the ice in deforming the surface plane of Lake Maumee.

The lowest beach of Lake Maumee is briefly mentioned by Mr. Leverett[2] but has not been described elsewhere. No systematic effort has been made to trace this beach except between Tecumseh and Rochester in Michigan, but it has been found at intervals northeastward as far as Romeo in Macomb County and southwestward nearly to the Ohio-Michigan State line. It has also been found at a number of places in Ohio eastward from Delphos and appears to be recognizable at many places by its influence on the contours of the topographic maps. It appears to be particularly well developed from the Defiance moraine eastward into Pennsylvania and was formerly regarded as the middle beach of Lake Maumee, the one above it being regarded as the highest. Now, however, this correlation is thought to be wrong and the two Maumee beaches which extend eastward from the Defiance moraine are regarded as the middle and lowest beaches, and the highest beach is thought to have been either not formed at all in the interval or else to have been overlapped or destroyed by the lake at the time of the middle beach.

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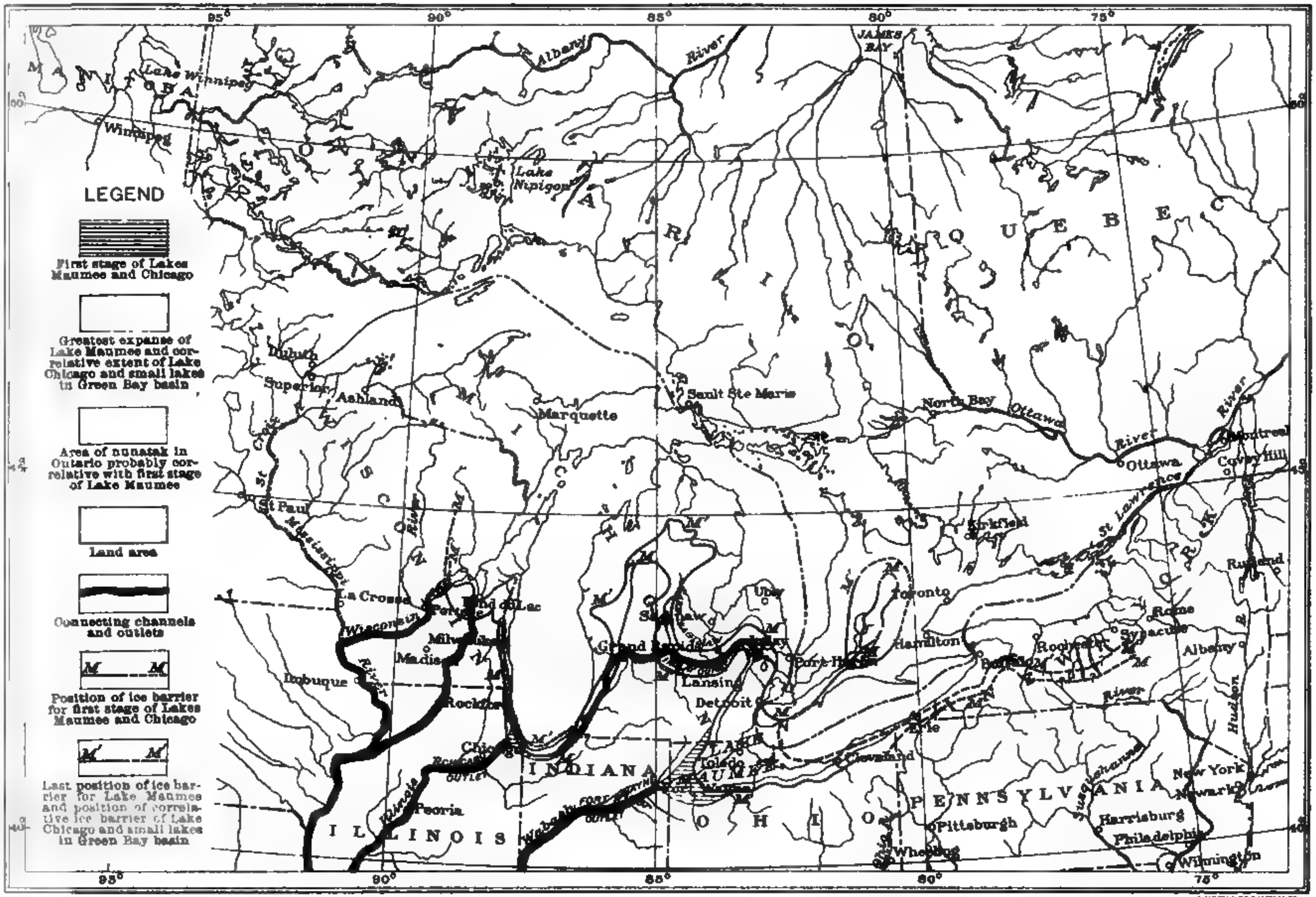
[1] Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 710–740. In this passage Mr. Leverett reviews earlier writings relating to this lake, including papers by Bela Hubbard, G. K. Gilbert, J. S. Newberry, C. R. Dryer, A. A. Wright, and others, and he notes the fact that the name Lake Maumee was first applied by Dryer in 1888, in his report on the "Geology of Allen County, Ind."

[2] Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1908, p. 7; revised ed., 1915, p. 7.

[3] Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 714–740.



MAP OF GLACIAL LAKES MAUMEE, SAGINAW, AND CHICAGO

By Frank Leverett and Frank B. Taylor
Data for eastern Wisconsin by Wm. C. Alden

100 0 100 200 300 Miles

1914

It seems quite certain that the highest beach is not represented in this interval by a strong separate shore line, like that west of the Defiance moraine, or it could hardly have been overlooked. That it was not formed east of the Defiance moraine seems improbable, because east of this same moraine in Michigan it is strongly developed in independent form and all three beaches extend up to the vicinity of the Imlay outlet. If it was made inside the Defiance moraine in Michigan, it should have been formed inside the moraine in Ohio. It is therefore regarded as possible that the highest beach in this interval stood at about the same level as the middle, and that fragments of the highest may lie in discordant relations behind the middle. More field studies bearing on this question are needed.

If the middle beach is, in fact, as high or higher than the first or highest beach on the south side of the basin east of the Defiance moraine but not west of it, the cause of such a relation is somewhat difficult to find. At present no satisfactory explanation seems available—nothing better than an arbitrary assumption of slight local subsidence of the land after the formation of the highest beach and before the formation of the middle one. If the highest beach were confined to the basin west of the Defiance moraine, both north and south of Maumee River, the relations would be simple enough, but such does not appear to be the case. Somewhat similar conditions occur in connection with the beaches of Lake Arkona but nowhere else, so far as is known.

CHARACTERISTICS OF LOWEST BEACH AND RELATED DELTAS.

Mr. Leverett points out[1] that the lowest beach has a "washed-down" appearance, as if it had been submerged and modified. Later investigations in connection with Lake Arkona (p. 362) have fully established the fact that beaches have been submerged and modified and in places have been almost totally destroyed. Certain characteristics qualities very clearly distinguish such modified beaches from others that have not been submerged, and these same characters are distinctly shown by the lowest beach of Lake Maumee. Even where composed of gravel, it is more fragmentary than other gravelly beaches, and at most though not at all points it has a lower relief than normal gravel beach ridges. In some intervals the beach deposit appears to be absent entirely, and in others it has a "washed-down" appearance and its ridges and gravelly deltas contain more clay and have a stiffer soil than normal beaches and deltas.

A characteristic feature of the Arkona shore lines is the remarkable way in which the deltas connected with them protrude beyond the general line of the shore. The Arkona delta of Huron River carries the beaches out into the lake 2 or 3 miles beyond the general lake border. In less degree the gravelly deltas associated with the lowest beach of Lake Maumee show the same habit of protrusion beyond the general line of the shore. This relation appears to be accounted for mainly by the fact that these deltas were built by streams entering the lake in beds that had not been previously trenched to or below the lake level of that stage. Neither at their mouths nor in their lower courses did these streams have any preexisting valley or bed in which the coarser sediments could lodge. Hence, all of their sediments were carried beyond the original contour of the shore and were deposited in a mass that carried that contour out into the lake. It was quite different with Lake Whittlesey, for that lake was superposed on a surface previously trenched by streams, and the trenches made by those streams absorbed nearly all the materials commonly built into deltas, so that Lake Whittlesey had no protruding deltas, but only estuarine or valley-set deltas.

Rouge River at Plymouth made a rather prominent delta in connection with the lowest beach, and the beach ridge associated with it is greatly strengthened. At Rochester the delta is not quite so prominent but has the common characteristics. At Ypsilanti the delta is very prominent and extends about 2 miles beyond the general shore line. East of Ypsilanti it contains one or two strongly marked distributary channels. The deltas south of Saline and Tecumseh are not so prominent, but they show the same modification by submergence.

These characteristics of the lowest beach and of the deltas associated with it seem to leave no doubt that this beach, although located farther down the slope, was made before the middle beach, and that after it was made the lake was raised to the level of the middle beach. While the latter beach was being made, the lowest beach was submerged and was undergoing modification.

[1] Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1908, p. 7.

TOPOGRAPHY OF THE BEACHES.

ALTITUDE.

The altitudes of the highest and middle Maumee beaches were originally determined by Mr. Leverett[1] mainly by aneroid barometer checked by railroad levels. The Survey's topographic maps covering the course of the beaches between Tecumseh and Washington in Michigan, including those of the Ann Arbor quadrangle, do not show any notable error in previous measurements. The maps of areas from Findlay to the western edge of the Delphos quadrangle indicate that the altitude of the highest and middle Maumee beaches and of the vicinity of the head of the outlet at Fort Wayne, Ind., is 5 or 6 feet higher than was previously indicated. In the following résumé of variations in altitude[2] the details are given somewhat fully, because some of them will be referred to later.

By the older measurements the altitude of the highest Maumee beach is 775 to 780 feet at the head of the outlet in the vicinity of Fort Wayne and New Haven, Ind. Near the Ohio-Michigan State line, 50 to 75 miles to the northeast, it is 20 to 25 feet higher. At West Unity and Fayette, Ohio, the beach stands close to the railroad stations, at an altitude of 801 and 798 feet, respectively. At Fairfield, Mich., the altitude of the geodetic station is 799 feet.

Mr. Leverett gives the altitude of the highest beach as 795 to 805 feet throughout the Ann Arbor quadrangle. The strong beach is generally above 800 feet and at a few points rises to 810 or 812 feet. Two points that reach above the 820-foot contour are thought to involve some error in contouring, for they seem too high for any phase of normal development even for a storm beach. If the measurements are correct, such forms are likely to have had some special mode of formation, such as the shoving of ice on shore by the wind or, more probably, some occurrence associated with the formation of the deltas of Huron River in Lake Maumee.

The highest beach continues at about the same altitude (800 to 810 feet) to a point 4 or 5 miles north of Birmingham, where it begins to rise. It is 805 feet 2 miles west of Birmingham, but at the north edge of the Rochester quadrangle, 1½ miles north of Washington, it is 820 feet. From Clinton River northward about 25 miles to Imlay the beach rises nearly 40 feet or to an altitude of 850 feet above sea level. The beach was traced by the writer to a fading termination, at an altitude of a little more than 855 feet, in northwest sec. 21, Goodland Township, Lapeer County, nearly 6 miles north of Imlay.

On the south side of Lake Maumee the early measurements made the altitude of the highest beach 775 to 785 feet from Fort Wayne to Cleveland. The new topographic maps show it to be 785 to 790 feet from Delphos to Findlay. Eastward from the Defiance moraine (see p. 279) the middle beach of Lake Maumee marks the limits of the lake, so far as yet recognized.

By early measurements the middle beach was found to have an altitude of 760 to 765 feet, or 20 to 25 feet below the highest beach from the head of the outlet east of Fort Wayne to Bryan, Wauseon, and Pettisville, Ohio. At Fairfield, Mich., it had an altitude of about 775 feet, and in the Ann Arbor quadrangle of 780 to 785 feet, almost everywhere 20 to 25 feet below the highest beach. It rises from 785 feet at Clinton River to 825 feet at Imlay. Toward Imlay it is 25 to 30 feet below the highest beach. East of Almont it is 821 feet above sea level and 19 feet below the highest beach. Its bars on the moraines at Smith station and Berville are 820 feet above sea level.

The middle beach is stated by Mr. Leverett[3] to have an altitude of about 765 feet between Fort Wayne and Cleveland. But the middle beach is not well developed in the vicinity of the outlet, and its identity and continuity among several weak ridges on the flat plain extending eastward from New Haven, Ind., into Ohio have not been fully worked out. Some of the lower of these ridges probably belong to the lowest beach, the place and relations of which in this district remain to be determined.

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[1] Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 723-739.
[2] Mainly from Mon. 41, the Ann Arbor folio (No. 155), and the new Survey sheets in Ohio.
[3] Mon. U. S. Geol. Survey, vol. 41, 1902, p. 739.

The middle beach enters the Delphos quadrangle at an altitude of 770 to 777 feet and holds it as far as Pandora. From Pandora to Benton Ridge it rises to over 790 feet and is associated with some exceptional features. (See p. 340.) It is in many places not more than 10 feet and in most places not more than 15 feet below the highest beach. In a few places the interval is greater than 15 feet. These variations of vertical interval are due chiefly to variations in development; where the highest beach is weak and the middle one strong the interval is less than the mean, and where the highest beach is strong and the middle one weak the interval is greater than the mean.

Eastward from the Defiance moraine the middle beach appears to mark the limits of Lake Maumee. It rises from about 770 feet near Leipsic to 780 or 782 feet near Berea and in Cleveland. From Cleveland northeastward to Mentor, a distance of a little over 20 miles, it rises to 791 feet. Eastward from Mentor it runs at nearly the same level about to Ashtabula, where all the beaches begin to rise. At the Ohio-Pennsylvania State line the beaches are all 8 or 10 feet higher than at Ashtabula, and from the State line they all rise more rapidly northeastward.

The lowest beach is weak and fragmentary but is fairly well defined in the Delphos, Columbus Grove, Bluffton, Ottawa, and Deshler quadrangles in Ohio. Its altitude is a little above 750 feet. Several points show 752 feet and others as much as 757 or 758 feet. In Michigan this beach is generally at or slightly above 760 feet, but in Ohio it averages about 755 feet. The lowest beaches near the Fort Wayne outlet are near enough to this level to suggest their probable identity.

So far as observed in Michigan the lowest beach is everywhere about 20 feet below the middle one. It has not been observed north of Romeo, in Macomb County, where it is a weak feature at about 790 feet, the middle beach being at 810 feet.

Since the discovery of the lowest beach some uncertainty has arisen as to the identity and northeastward extent of the middle and lowest Maumee beaches, but there has been no opportunity to reexamine the ground. It seems likely, as stated above, that the delta-like deposits at Fairview, Pa., and the faint beach and delta deposit at Girard, Pa., belong to the lowest beach. Their height above the Whittlesey beach indicates this, and if such is their relation it may be that somewhere west of Girard the middle beach becomes too weak to be traced. However, if the lowest beach was made at a back-step halt of the ice front and the middle beach after readvance and a raising of the lake level, as supposed, then some part of the lowest beach was overridden and obliterated by that readvance. The middle beach would then be faint at its end and could not, in all probability, be traced so far to the northeast. The deposit at Girard, Pa., has an altitude of 770 to 775 feet and is 25 or 30 feet above the Whittlesey beach.

A careful comparison of altitudes seems to show all the beaches in the Oberlin quadrangle to be a little low, possibly because they are protected against the dominant western winds by the high ground in the Vermilion quadrangle to the west. The fact, however, that all beaches are affected alike, although all are not equally protected, renders this explanation somewhat unsatisfactory.

ICE RAMPARTS.

RAMPARTS ON MODERN LAKES.

In Indiana, Michigan, Iowa, Wisconsin, Minnesota, and probably elsewhere there occur what are known as "walled" lakes[1]—lakes bordered on one or two sides by a narrow ridge or wall of bowlders a few yards back of the shore. Such ridges, called "ice ramparts," are commonly 2 to 5 feet high and on some lakes run for long distances. Modern ramparts invariably rest on flat ground and face lakeward over a flat shore and a shallow, smooth lake bottom from a few rods to several hundred feet wide.

Ice ramparts are the product of wind and floating ice, the ordinary ice coating of the winter season. Toward spring the ice covering the lake thaws around the edge, becomes loosened from

[1] One of the best accounts of these lakes and of the formation of rampart ridges is by E. R. Buckley (Ice ramparts: Trans. Wisconsin Acad. Sci., vol. 13, 1901, pp. 141-162). Dr. C. A. White also discussed walled lakes in his official report as State geologist of Iowa, published in 1870.

the shore, and then by heavy gales, usually from a westerly direction, is driven with great force upon the easterly or southeasterly shores. On ordinary shores with bluff banks and steep descent the ice simply batters the shore and breaks up, producing no unusual result. But if the offshore slope be very gentle and the ground back from the water's edge low and flat, the ice meets relatively slight resistance and by sliding on the bottom rides up out of the water onto the land, sometimes pushing scores of feet beyond the water's edge.

In sliding up the gentle incline the ice is cracked at intervals, but the pieces are usually not disjointed nor separated and the whole mass is pushed forward with tremendous force, carrying everything movable before it and gathering up a ridge of mixed materials to be finally left in the form of a rampart.

RAMPARTS ON LAKE MAUMEE.

INTERPRETATION.

So far as the writer is aware, the occurrence of this process on a large scale in the past has not been clearly inferred from anything observed hitherto, but in the district under consideration a remarkable group of ridges associated chiefly with the highest beach of Lake Maumee shows peculiarities of form, composition, and general relations that are inexplicable, except on the supposition that they are ice ramparts. On this supposition all of their peculiarities are clearly explained. These ridges occur on the south shore of Lake Maumee, chiefly between Delphos and Findlay (see Pl. XV), where the trend of the old shore is southwest and northeast. Their principal development is between Gomer, 8 miles east of Delphos, and Benton Ridge, 22 miles northeast of Gomer.

The ice ramparts of Lake Maumee are in many respects very different from the forms common on the shores of the small lakes. In the first place the whole phenomenon is on a scale many times greater than that of the small lakes. Instead of being composed mainly of bowlders, pebbles, and rubbish, those of Lake Maumee are composed chiefly of gravel and clay, the clay in many places making more than half the mass.

The early students of this region appear to have paid no special attention to these ridges but to have regarded them as ordinary beach ridges. Although their situation and relations to the shore of Lake Maumee and to the beach ridges mark them as closely related forms, their clayey composition excludes them from the category of true wave-made deposits. They show also peculiarities of plan and general relations that are abnormal for beach ridges formed under the very simple conditions of this district, where the country for several miles north of the beaches is extremely flat and even, its general slope being north-northwest 5 to 10 feet to the mile. The extreme shallowness of the lake waters for several miles offshore was probably not equaled elsewhere in the lake region. More particularly was this true when the lake was first formed and the waves had not yet had time to modify the lake floor.

Normal beach formation on such a shore generally results in the formation of beach ridges on straight or very gently curving lines following the course of a contour. It does not tend to the formation of crooks nor sharp bends, nor, with only small streams and low gradients, to the formation of notable delta irregularities. As the present stream beds of the region are narrow and only slightly depressed in the flat plain and were less depressed in glacial times than now, there appears to have been no cause in the topographic environment for exceptional or peculiar beach forms.

DISTRIBUTION AND CHARACTER.

Within 3 miles of Columbus Grove, four branch ridges, 3 or 4 miles long, appear to split off from the south side of the middle beach of Lake Maumee and run southwest a little more south than the main ridge. These branch or spur ridges are more like true beach ridges than the fragments east of Pandora, because they have suffered less modification. They appear to be connected with the middle beach but are mostly higher, especially toward their southwest ends, where they rise to the level of the highest beach.

These spurs have four marked peculiarities: (1) Their southwest ends all bend sharply south, leaving the direct lines of continuation unoccupied; (2) most of them show angular crooks and turns that are plainly not normal to the conditions of beach formation in this district; (3) they divert the course of the streams toward the northeast, which is contrary to the direction that would be expected if they are true beach bars built by waves; (4) though their composition varies considerably they contain much clay, in many places more than 50 per cent.

The southwest direction in which the spur ridges split off is such that they could have been built as spits or bars only by shore drift coming from the northeast. If so built they must have been made before the building of the Defiance moraine, for since that moraine was built the dominant wave action and shore currents were from the west and southwest, and the wave action and shore currents from the northeast were relatively weak because of the narrow expanse of water in that direction. Their relations, however, are such that they could not have been built from that direction.

One of the most striking peculiarities of the spur ridges is the bent end which characterizes each. Six or seven such ends occur between Gomer and Columbus Grove and several other less prominent ones farther east. Their relations to the streams and their horizontal plan are shown on Plate XV.

One of the spur ridges which terminates a mile east of Vaughnsville is about 2½ miles long. Most of it is straight and simple in form, its chief peculiarity being its bent end and the relation of this to Sugar Creek. In shape it resembles a hockey stick, the sharply bent end at the southwest corresponding to the bent end of the stick. It looks as though the ridge had originally extended in a straight line southwest to the creek and had there been united directly with the ridge on the west side, the end of which, now one-third mile away, is not bent. The ridge does not come up to the bank of the creek on the east side nor does the opening contain deposits representing the ridge. If any were ever there they must have been removed. The bent end is of the proper length to supply the missing part, and the effect is as though the end east of the creek had been pressed or pushed back a quarter of a mile or more by some agency acting from the west or northwest.

The bent end looks like an inward curving spit or hook on the map, but it is in reality not of that nature. The environment is not that which favors the making of hooked spits but is typical of that which leads to the making of straight-line or very gently curved beach forms. The ground on which the ridge rests is extremely flat. The stream even now is only slightly depressed where it passes through the ridge, and at the time Lake Maumee existed the depression was certainly much less. No wide, shallow troughs are associated with these streams, as is plainly shown by the contours of the topographic maps and by the remarkably even, nearly straight course of the middle Maumee beach ridge westward from Columbus Grove. This beach shows that at the time of its formation there was no inequality of the land surface of sufficient magnitude to counteract the normal tendency to the formation of rectilinear shore lines. Conditions were similar during the formation of the highest beach and of the spurs with bent ends.

There appears to have been no reason for the formation of hooked spits at the places where the bent ends are found. There was no depression or valley toward the south up which they could turn. Indeed, these bent ends usually run up onto ground somewhat higher than that where the spurs split from the main ridge. Two miles south of Columbus Grove and in one or two other places the bent end is wider and higher than the rest of the spur, as though the material of a section of the spur had been pushed obliquely into a smaller space.

Most of the spur ridges show peculiar crooks or sharp bends that resemble the angles of the bent ends, but in which there is no break. Good examples are shown south and southeast of Vaughnsville and south and east of Columbus Grove. This peculiarity is just as abnormal as the bent ends for true beach formations under the simple conditions of this district.

In another way these forms are decidedly abnormal. In the making of beach ridges on shores conditioned like this, the gravel and sand for the building of the ridges is not derived from the cutting of sea cliffs nor in any important degree from sediments brought in by small streams like those of this district but is gathered mainly from the bottom of the lake in the shallow

water offshore. Where the water is shallow for a long distance out, storm waves break at a considerable distance off shore and do a great work of erosion upon the bottom. They pound it and stir it up, ultimately carrying away the finer sediments to deeper water and sweeping the coarser sediments up the slope into a beach ridge. Thus, in front of a beach ridge of fairly mature development, there is commonly a belt of considerable width—a "surf-wasted zone"—which has been cut away by the subaqueous work of waves and currents. None of the spur ridges of this district has a surf-wasted zone. In strong contrast, the middle beach of Lake Maumee, a mile or so away, has a well-developed zone of this kind.

When to the several peculiarities adduced is added the clayey composition of the ridges, it becomes impossible to explain them as normal, unmodified products of wave and shore current action. But, as will be pointed out below, all of their peculiarities are clearly explained if the ridges are regarded as ice ramparts.

East of Pandora the rampart ridges have somewhat different expression. They are more nearly straight but vary more in strength and height and are more largely composed of clay. Some of their higher parts reach an altitude of 800 feet. The highest beach of Lake Maumee has an altitude of 785 to 790 feet, and the ridges east of Pandora seem quite clearly to belong to the time of that beach, as do also some smaller, scattered fragments 3 miles south of Pandora and 3 to 4 miles southeast and south of Columbus Grove.

From Pandora to Benton Ridge the middle Maumee beach seems to rise 15 feet and runs obliquely across the trend of the rampart ridges. It has the appearance of having been superposed upon the rampart ridges, and there is reason to believe that the ramparts formerly extended fárther to the northeast on ground which is now below the level of the middle beach.

FORMATION.

In its early stages Lake Maumee was in all probability covered with ice of considerable thickness during winter seasons. In the spring the margin of the ice, where it had been attached to the shore, was the first to thaw, leaving a lane of open water between it and the land. The ice had thus become loosened from the land and floated freely on the water. While in this condition, strong winds from the west or northwest drove it toward the east or southeast, and the force of the wind and the momentum thus attained carried it up the gentle slope.

In this district the shore and lake bottom conditions at the time of the highest beach of Lake Maumee were extremely favorable for the formation of ice ramparts. When the vast ice cake or floe impelled by the wind began to move toward the shore its lower edge first encountered the gently sloping clayey bottom of the offshore shallows. This offered relatively little resistance. A considerable body of the mud with whatever was resting on it was pushed forward at the edge of the ice. At length the upward inclination of the bottom raised the marginal part of the ice slightly out of its horizontal position and made it conform to the plane of the slope. Probably the ice was cracked at intervals in this process, but it was not broken up and displaced. When the edge of the ice reached the beach line, the materials which the waves had gathered were incorporated with the mud and pushed along up the slope. When the shoreward movement of the ice stopped, this body of clay, gravel, and sand was left as the rampart ridge. The bent ends were pushed back at the edge of ice moving from a northwesterly direction, and the crooks and thickened ends were produced and the clay contributed in the same way. Such a process requires no notable depression in the gap west of the bent ends nor any surf-wasted zone in front of the spurs.

In all probability the ice cakes involved were generally several miles in extent along the shore. This is indicated by the length of the rampart spurs. That the ice cakes were not much broken along their shoreward edges is also indicated by the straightness of most of the longer spurs. Still the occasional sharp bends and the bent ends may be in part due to cracking of the ice on lines normal to the shore and to unequal shoving of the different parts. Whether the ramparts are in each case the product of a single onshore movement or are the cumulative product of a few or of many such movements can not now be stated. The latter alternative would seem the more likely one, but very little evidence supporting it was observed.

The larger scale of the forms in this district as compared with modern features of similar origin points to some interesting conclusions relating to the conditions which existed at that time. It was stated above that most of the rampart ridges seem to be related to the time of the highest Maumee beach. It is worthy of note that the conditions were more favorable for on-shore movement of the ice then than at later times, for, when the continental ice sheet first withdrew from this ground and Lake Maumee first occupied it, the slopes from the lake bottom 4 or 5 miles offshore to the land surface a few miles back of the shore were more even and uniform than they have been at any later time, because they had not then been modified either by surf-wasting offshore or by the building of beach ridges on shore. Hence, the first ice cakes that were blown on shore met less resistance and probably pushed farther up the slope than any of the later ones. As the surf-wasted bench became more pronounced in its development and the beach ridges larger and more bulky, the conditions favoring the shoving of ice floes above the shore line grew less marked. For this reason the highest of the ramparts and those farthest back were made first and the series down the slope to the northwest were made successively later. The older ridges generally contain more clay than the later ones. Some of the fragments and bent ends indicate displacements amounting to a mile or more, and in some places the displacement may have been even greater.

As the shore of Lake Maumee westward into Indiana is of the same character and the beaches westward from Delphos show very little modification of the kind here described, it seems certain that the westerly and northwesterly winds were the chief forces that produced the on-shore shoving of the ice. That part of the shore that faces the northwest or north-northwest shows the strongest development of ramparts. The shoving seems to have been done mainly from the west-northwest or in a direction slightly oblique to the slope. This, of course, had the effect of reducing the relative degree of inclination of the slope up which the ice moved and facilitated the process. In general the bent ends and sinuosities seem best accounted for by shoving from the west-northwest.

If the beachlike clayey ridges of this district are in fact ice ramparts and were produced in the way here suggested, their magnitude and the scale of the movements involved in their displacement seem to require thicker ice in the ice cakes or floes on Lake Maumee than occurs on any modern lakes. Ice at least 5 to 10 feet thick seems indispensable to the validity of the explanation here offered. But a greater thickness of the winter's ice on Lake Maumee might be expected in the glacial period when the front of the continental ice sheet was probably not more than 40 or 50 miles away. It is not impossible that a more detailed study of these forms would lead to more definite conclusions as to the thickness of the ice at that time.

After the surf-worn bench offshore became strongly developed, on-shore shoving of the ice ceased to be so important, but apparently it did not cease to play a part in determining the composition of the beach ridge in some localities. The middle beach ridge a mile or two east of Delphos is composed largely of clay, and the upper ridge in Van Wert was found by Mr. Leverett [1] to contain clay. In all probability these characters are due to the same process of on-shore shoving of floating ice by the wind—an action which, though strong enough to push much clay up onto the beach, was too feeble to break or displace the ridge as it had done formerly. The lowering of the lake level from the highest to the middle Maumee beach reduced the offshore depth and tended to favor a renewal of rampart making. But the slope back from the water's edge was less favorable, being steeper than formerly, and probably caused the ice cakes to break up against the beach ridge.

OTHER GLACIAL RAMPARTS.

Somewhat similar effects on a smaller scale may have been produced in other localities in the Great Lakes area. Some may be associated with the Whittlesey, Arkona, and Warren beaches in the flat regions in Ohio north and northeast of the district here described. In the Quanicassee region at the southeast side of Saginaw Bay some of the heavy ridges may be largely

[1] Mon. U. S. Geol. Survey, vol. 41, 1902, p. 728.

due to ice shoving, for in January, 1910, a gale from the west-southwest piled the ice of Saginaw Bay on shore near Sebawaing into a ridge 10 miles long and in some places 70 feet high. The floor of the shallows there is flat limestone.

DEFORMATION OF WATER PLANE BY ICE ATTRACTION.

THEORETICAL CONSIDERATIONS.

It has been calculated theoretically by Woodward [1] that an ice sheet of a certain thickness, configuration, and extent would draw up the water surface of a lake standing in contact with it by a certain definable amount. Woodward's statements are often quoted, but a careful examination of his paper makes it clear that the conclusions usually drawn from them are unwarranted.

Woodward adopts certain definite assumptions as the basis of his calculations. He assumes an ice cap at its center 10,000 feet thick, covering the polar regions and extending symmetrically to the thirty-eighth parallel. Then he gives a series of values for the deformation of the water plane based on different assumptions as to the slope of the surface of the ice cap from its center to its edge. One of these assumptions is that the ice cap is of uniform thickness throughout (has no slope from center to edge); that is to say, that it is 10,000 feet thick at its edge on the thirty-eighth parallel and that its front is a vertical cliff of ice 10,000 feet high. For this particular assumption Woodward finds that the water will be raised 573 feet at the edge of the ice cliff and will slope away at an average rate of 1 foot to the mile for a distance of 1° from the ice edge. This assumption, though very far from the conditions of the concrete case under discussion, is invariably the one quoted, and this despite the fact that Woodward gives results for several other assumptions which come much nearer actual conditions. No attempt is made here to apply Woodward's analysis to the concrete cases found, but it seems worth while to present certain facts bearing on the problem.

AREA OF HORIZONTALITY.

Several places within the Great Lakes region might be expected to afford a test of this theory, and it is important to examine the data in these localities and to place the facts on record for the use of any who may wish to pursue the inquiry further. If the old shore lines show the supposed deformation by ice attraction, it is desirable to determine its amount and to recognize it so that it can be eliminated from the estimates of the amount of deformation due to other causes, where greater deformation occurs, and also in order that regions unaffected by other causes of deformation may be recognized clearly and the slight deformations due solely to ice attraction distinguished. The localities where the theory might be tested are not all in the area under discussion, but they may be considered briefly.

In discussing the deformation of the Great Lakes region it has for some years been regarded as a fact that all the beaches south of a certain ill-defined line or narrow zone are horizontal. The line runs from Ashtabula, Ohio, through the central part of Lake St. Clair, passes 4 or 5 miles north of Birmingham, Mich., and crosses Lake Michigan westward from a point a few miles north of Grand Haven. South of this line the old water planes depart so little from horizontality that the departures were regarded as possible errors of measurement, or as lying within the limits of the natural range of altitude of normally developed shore formations, or as due in part to ice attraction. This was more particularly the attitude of mind of students of the subject before the publication of the more accurate topographic contour maps made in recent years by the United States Geological Survey. In certain districts now covered by these maps more refined studies can be made, but the maps now cover only a few limited areas.

The line referred to above was taken to be the isobase of zero, or line of no deformation. Apparently the land to the north of it has been uplifted and deformed, and the land to the south of it has remained unaffected and in its original attitude of horizontality. In this sense the isobase of zero has been called a "hinge line" and the region south of it is the so-called "area of horizontality."

[1] Woodward, R. S., On the form and position of the sea level: Bull. U. S. Geol. Survey No. 48, 1888, pp. 13-86.

DEFORMATION AT OR NEAR THE EDGE OF THE ICE.

DEFORMATION BETWEEN COLUMBUS GROVE AND FINDLAY.

Field work.—Considered with reference to accuracy and reliability of data the district between Columbus Grove and Findlay, Ohio, affords the best field for the study of ice attraction now available. (See fig. 4.) In this district the area occupied by the highest and middle Maumee beaches is covered by some of the newly made topographic maps with contour intervals of 10 feet. Ice shoving, which occurred chiefly in connection with the highest beach (see p. 338), modified it so extensively that its tracing eastward from Columbus Grove is very uncertain; however, it does not appear to rise in that direction. It seems certain that the highest beach in this vicinity was made before the Defiance moraine and extended a considerable distance farther east, being overridden by the readvance to this moraine.

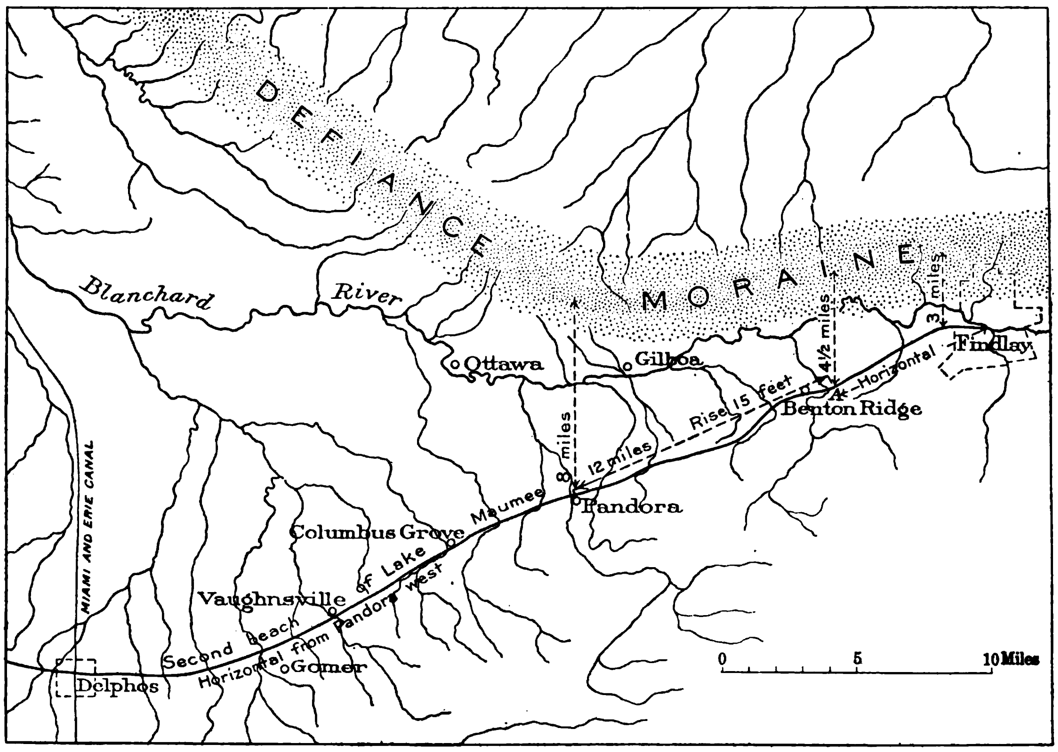

FIGURE 4.—Map showing relation of the second or middle Maumee beach to the Defiance moraine west of Findlay, Ohio.

It was pointed out that the middle beach appears to be superposed on the rampart ridges between Pandora and Benton Ridge and that it there rises very perceptibly. Westward from Pandora to a point about 8 miles west of Delphos, which is as far as mapping has been completed, the middle beach appears to be horizontal, the altitude on its crest varying from 771 to 777 feet, the lower figures being apparently on parts not fully developed. Northeastward from Pandora the beach appears to rise.

Northeastward from Pandora the middle beach (see p. 340) seems to be continued in the strong but somewhat bent and broken line which rises from Pandora to Benton Ridge and Findlay. Mr. Leverett [1] describes it as follows:

> Between Pandora and Findlay the beach is very strong as far as Benton Ridge, there being usually a bank 10 to 20 feet high, capped by gravel several feet in depth. From near Benton Ridge to Findlay the bank is but 6 to 10 feet high and the deposits are rather sandy. This part of the beach borders a narrow bay south of the Defiance moraine, and in view of its situation is remarkably strong.

[1] Mon. U. S. Geol. Survey, vol. 41, 1902, p. 729.

More recently, with the topographic maps in hand, the writer reexamined the district and received the same impression as to the continuity of the middle beach from Pandora to Benton Ridge and Findlay.

The Survey's topographic maps show that the rise does not extend all the way to Findlay but that several small parts of the crest rise to or a little above 790 feet above sea level a mile or more west of Benton Ridge and that an increasing proportion rises to this height farther east. Some of the beach crest to the west of Benton Ridge is mainly sand, but that to the east is largely gravel, though of sand in some places and clayey gravel in others. About 1½ miles east of Benton Ridge the crest is mainly above 790 feet, but it seems to rise no higher farther east, continuing about the same to the bend 1½ miles west of the courthouse in Findlay. Eastward from this point the crest appears to decline a little, but apparently only because it is more faintly developed.

From Pandora to Benton Ridge, and less conspicuously from Columbus Grove to Pandora, the middle beach has a mildly scalloped front made up of a series of curved sections convex toward the north-northwest and joined end to end. The west halves of most of the scallops trend southwest and are in fact parts of one of the preexisting rampart ridges changed only a little by the waves, in some places by erosion, but generally by an overcoating of sand and gravel. The east halves of the scallops trend east obliquely across the courses of the rampart fragments and are parts of a new-made ridge constructed by the waves to bridge the gap from one rampart ridge to the next one east. Where the newly built section meets the next older rampart there is a reentrant angle of the shore—a wave-built beach running east and abutting against the face of an older clayey rampart running northeast. It was in this way that the middle Maumee beach acquired its scalloped form east of Columbus Grove. Where the trend in this interval is northeast to southwest the main body of the ridge of the middle beach is generally one of the older rampart ridges. At many places, especially on the inner slope, the clayey gravel may be seen. For 2 miles northeast from St. John's Church and for 3 miles southwest from Benton Ridge the beach seems clearly to be superposed on a rampart ridge. At the latter place especially this relation seems certain, for at the southwest, where the middle Maumee beach turns away to the west, one of the finest of the rampart ridges runs on southwest behind the middle beach in perfect continuity in its precise trend from Benton Ridge.

The whole rise of the middle beach appears to be between Pandora and a point 1½ miles east of Benton Ridge—a distance of about 12 miles and a rise of 15 feet, or from an average altitude of about 775 feet to a little more than 790 feet above sea level. The rate of rise is therefore a little more than 1.2 feet to the mile.

To the meridian of Pandora, 16 miles on a line directly west from Findlay, the Defiance moraine runs a trifle south of west, but north of Pandora it turns northwestward. On a line directly north from Pandora the crest of the moraine is 8 miles away, and north of the bend of the beach 2 miles west of Findlay it is scarcely 3 miles away. This part of the beach, therefore, is not exactly parallel with the crest of the moraine, but in 16 miles it draws only 5 miles nearer, or from 8 to 3 miles. From Ottawa Creek, a mile east of Benton Ridge, to Findlay the beach is more nearly parallel with the moraine than it is farther west, and this part is apparently about horizontal at a little above 790 feet.

Two to three miles north of Gilboa faint and fragmentary indications of a shore line appear along the crest of the moraine for about 4 miles at an altitude a trifle above 790 feet, the precise altitude being difficult to determine because the deposit is mostly fine sand and somewhat wind blown.

Mr. Leverett's studies on the Maumee beaches on the inner or northern slope of the Defiance moraine show only the middle and lowest Maumee beaches to be present. The Defiance moraine thus appears definitely to limit the eastward extension of the highest beach on this side of the lake and at the same time to draw the middle beach up out of the horizontal plane. This is on the supposition that the ice front was resting on the moraine when the inclined section of the beach was being made.

In general the relation of the inclined part of the beach to the moraine and to the ice front resting on it is what might be expected as a normal result of the attraction of the ice sheet, but in detail some rather serious difficulties present themselves. As pointed out above, the inclined part of the beach approaches the front of the moraine on an oblique line, rising 15 feet in 12 miles. But the true amount of deformation of the old water plane is found by measuring it on the line of maximum deformation, which in this case would be on a line normal to the ice front.

If the beach rises from Pandora 15 feet on an oblique line ending 3 miles south of the moraine, the same amount of ascent would take place in a shorter distance on a line normal to the ice front. Pandora is 8 miles south of the crest of the moraine. The altitude of the beach 3 miles south of the moraine on this line ought to be the same as it is at the end of the oblique line the same distance from the moraine, the two localities being so close together and there being no change in the value of the larger factors of deformation. But if this be true the beach would rise the observed 15 feet in going 5 miles north from Pandora, or at the rate of 3 feet per mile.

If the plane of the rising beach is carried up to a position in contact with the front of the ice represented as resting on the crest of the moraine, the rising beach must be followed 3 miles farther north, and even if its rate of rise is assumed to continue without increase it is necessary to add 9 feet to the 15 feet of rise already found. But, theoretically, the rate of rise should increase toward the ice. It seems certain, therefore, that this much additional rise must be assumed on a line going north from Pandora, and this would lead one to expect the beach on the crest of the moraine (supposing the moraine high enough to have the beach recorded upon it) to have an altitude of at least 800 feet. But the end of the line running 8 miles north from Pandora rests on the sandy belt at an altitude of 790 to 795 feet. Another difficulty arises from the fact that the inclined part of the beach appears to come to a sudden end at Pandora, the beach being horizontal beyond that point. It would seem as though deformation by such a cause would give the water surface a gradual and progressive diminution of inclination in going away from the ice front, one which would take the form either of a parabola or of a hyperbola when seen in vertical section. The facts in this locality indicate that if ice attraction is the cause of the deformation it drew the water surface up 25 or 30 feet in 8 miles from the edge of the ice, but had no appreciable effect at a greater distance. In other parts of the area of horizontality, however, there are facts which may be regarded as evidences of the attraction of the ice sheet at a distance. (See pp. 346–348.)

Application of theory.—On the assumption that the ice sheet maintains a thickness of 10,000 feet to its edge (p. 342) Woodward calculates that the water surface at the edge of the ice would be drawn up 573 feet and would slope away at a rate of 1 foot to the mile. On the assumption that the ice sheet slopes 18.34 feet per mile, which is in all probability less than its actual slope, he calculates that the water surface at the edge of the ice would be drawn up 326 feet. The observed effect, if rightly stated above, is less than one-tenth of this amount.

When it is considered that the Maumee ice lobe protruded considerably forward from the general front of the ice sheet, that it was in all probability a relatively thin body, and that by the time the ice front had retreated to the Defiance moraine the thickness of the ice sheet at its center was probably not over 5,000 feet, it is easily seen that the real values for the effects of ice attraction in the Great Lakes region are more likely to be of the order of magnitude of the slight deformation indicated by the features found west of Findlay than by the much larger values found by Woodward.

On a rough calculation, based on Woodward's assumption of an ice cap covering the northern hemisphere completely down to the thirty-eighth parallel of latitude and having a uniform thickness to its edge of 10,000 feet, it seems probable that the combined mass of all the actual ice sheets in the northern hemisphere, even at their maximum extent, was not more than one-fiftieth of the mass of Woodward's assumed ice cap. When the ice sheets had dwindled to the stage marked by Lake Maumee, this combined mass was scarcely more than one seventy-fifth or perhaps one one-hundredth. The smallness of these values is due largely to the fact, now well established, that there was no polar ice cap, like that assumed by Woodward, but

that the real ice sheets were relatively local and restricted bodies, spreading from centers of growth in Labrador, Keewatin, Patricia, British Columbia, and Scandinavia.

In thinking of this problem it is necessary to remember that most of the ice Woodward reckoned upon was far away—half of it being distant over 90° of longitude and more than 38° of latitude—and had therefore a relatively small effect on the total result. It was the ice that stood near the lake that had the greatest effect and constituted the chief factor of deformation. It is not surprising, therefore, that such small values have been found for its attraction.

The features of this district bearing on the attraction of the ice sheet and its effect in deforming the lake surface are suggestive and in a general way appear to be confirmatory, but they fail in some important respects to accord with expectation based on what is believed to be sound theory.

DEFORMATION EAST OF DEFIANCE MORAINE.

As noted above, the limits of Lake Maumee in the region east of the Defiance moraine appear to correspond in altitude with the middle beach of Lake Maumee west of that moraine. It was formerly supposed that this beach extended about to Ashtabula, Ohio, without measurable tilting or deformation. But since the making of the topographic maps it is found that beginning about at Cleveland this beach makes a relatively rapid rise to the vicinity of Mentor and Painesville. The distance is 25 to 28 miles and the rise about 10 feet, an amount which seems to accord fairly well with deformation found between Pandora and Findlay.

The situation is much the same as that in the district just discussed, except that the contemporary position of the ice front is not accurately known. At the time of this beach the margin of the ice lobe in Lake Erie probably ran nearly parallel with the south shore and not a great distance from it.

DEFORMATION IN FORT WAYNE DISTRICT.

In discussing the first Maumee beach Mr. Leverett[1] states that near the vicinity of the Fort Wayne outlet this beach stood at 775 to 780 feet. Near the Ohio-Michigan State line several observations unite in giving the beach an altitude about 26 feet higher—at West Unity, Ohio, 801 feet, at Fayette 798 feet, and at Fairfield, Mich., 799 feet, these points all being close in front or west of the Defiance moraine. Northeast from Fairfield, on the inner or east side of the Defiance moraine, the altitude of this beach seems to be slightly lower.

Although this district lies within the "area of horizontality" and is therefore important in the investigation of this question, topographic mapping has not yet been extended into it and it seems too soon to discuss it. Other localities in the area of horizontality are found on the shores of Lake Michigan southward from Grand Haven, but accurate surveys of them have not been made.

Several other localities seem at first to afford promising places for studying the effects of ice attraction. One is the highest Maumee beach between Birmingham and Almont or Imlay, Mich.; another is the Whittlesey beach from Richmond to Applegate or Carsonville, Mich.; another is the Whittlesey beach between Dunkirk and Alden, N. Y., and still others are in Ontario. But all of these are in the region of stronger uplift from other causes and it would seem hardly profitable to attempt to unravel their complex phenomena.

ATTRACTION AT MODERATE DISTANCES FROM THE ICE.

Variations of altitude other than those described above (p. 344) for the Maumee beach are noticeable. Between Leipsic and Berea, Ohio, a distance of 115 miles, the middle beach rises about 10 feet, or about 0.08 foot to the mile. Variations like this, amounting to 10 or 20 feet in 100 miles or more, probably occur in other places. It seems quite probable that such a rise occurs between the head of the outlet near Fort Wayne and Findlay in connection with the highest beach. Mr. Leverett found the hooked spit on the east side of the Sixmile Channel at New Haven, Ind., to have an altitude of 786 feet, its crest being 2 or 3 feet higher than the

[1] Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 724–725.

average crest of the highest beach. It seems probable, therefore, that the highest beach rises in this interval from 783 or 784 feet to 790 feet, the distance being about 75 miles and the rate of rise, therefore, about 0.1 foot to the mile. The same gentle rise of the highest beach probably occurs between the head of the outlet near Fort Wayne and some point northeast of Bryan, Ohio, but accurate data for its determination are not now at hand. Again, from the vicinity of Fairfield, Mich., to Birmingham the beach appears to rise between 5 and 10 feet, the distance being about 65 miles. But in this last area there may be some complication.

The long, gentle slopes of the Maumee beaches, 0.1 foot or less to the mile, may represent the effect of ice attraction at a distance from the front. It is an extremely small deformation, but it seems more nearly what one would expect from a relatively small, thin ice lobe, like that related to Lake Maumee at the stages in question, than the larger deformation of 1 foot to the mile in the case worked out by Woodward.

Near Findlay and near Cleveland and at perhaps two or three other localities the beaches seem to record a relatively short, steep rise of the water plane at the immediate front of the ice. The long, gentle slopes of the beaches described here seem to represent the effect of ice attraction at a distance and stand in obvious contrast to the other effect. Considered as results of ice attraction, both of these phenomena seem normal in their distribution with regard to the ice sheet and with regard to each other.

It would seem utterly hopeless to look for such small effects of deformation as the long, gentle slopes described above in areas where other causes of deformation have operated. Only in the so-called area of horizontality, where other causes of deformation seem not to have operated, or to have been of a still smaller order of magnitude, could such slight deformations be recognized.

In the area of horizontality all the shore lines below the Maumee beaches, except two of the Arkona beaches which converge slightly southward, appear to be perfectly horizontal; that is to say, their variations of altitude appear to be so small that they fall well within the limits of variation which attend the formation of all beaches on account of the varying height of the deposits from point to point along the shore. This fact has in it something of the quality of confirmation of the supposition that it was ice attraction which produced the two peculiar deformations of the Maumee beaches described above, for the ice front was not near by when those later beaches were formed at lower levels, and the ice attraction can hardly be considered as an appreciable disturbing factor. The first and second Arkona beaches appear to merge southward in one, only two ridges occurring in Ohio. (See p. 372.) The cause of this relation is obscure and seems hardly referable to ice attraction.

Some doubt, however, remains as to whether the two classes of deformation ascribed to ice attraction are, in fact, represented in an unmixed way in the phenomena described. Certain other factors, such as strong winds, may have operated to raise or lower the water of the lake and with it the zone of wave action. The deformations that produced the long, gentle slopes were not much greater than the disturbances of lake level observed in recent years on Lake Erie. The wind effects, however, are not distributed like the deformations, for it is of record that a heavy northeaster has raised the lake at Toledo about as much as a heavy southwester has at Buffalo.

The main part of the large deformation of the old shore lines farther north is ascribed by most students to resilience following depression by the weight of the ice sheet. But when the ice sheet of the Wisconsin invasion was at its maximum it reached 50 to 100 miles beyond the southern shores of Lakes Maumee and Chicago and covered all of the area of horizontality, so far as its limits are indicated by the beaches.

Though this area was not subjected to the maximum ice weighting, it was nevertheless subjected to very considerable pressure—enough to lead one to expect at least some small resilience on its removal. But the distribution and relations of the small deformations observed within the area of horizontality do not appear to be in accord with such a cause. Furthermore, if there has been even a very slight deformation due to ice weighting and resilience it could hardly fail to complicate and obscure in greater or less degree the deformation due to ice attrac-

tion. All the deformation found in this area seems to accord better with ice attraction than with any other cause that has been suggested.

It is therefore concluded, provisionally, that the land in the area of horizontality has in fact remained practically unaffected by the great deformations which uplifted and tilted the region farther north. This area appears to have remained like a steady point while the region north of it was undergoing large changes of altitude and attitude. The area of horizontality may be used, provisionally, therefore, as the measure, not merely of relative movements, but of the absolute movements of elevation which have affected the deformed area farther north since the beginning of Lakes Maumee and Chicago. But it is not certain that this use has any application to times earlier than the beginning of these lakes.

The first and second Arkona beaches show a slight convergence toward the south in the northern part of the area of horizontality. In the vicinity of Birmingham the first Arkona beach appears to be 6 or 7 feet above the second, and this relation continues without noticeable change to the vicinity of Ypsilanti. Southward the second Arkona beach seems to rise gradually until the interval between it and the first is only 2 or 3 feet, and it finally pinches out entirely, so that in Ohio one beach appears to stand in the place of the first and second. This phenomenon may be due to an entirely different cause from that which affected the Maumee beaches, but it is of about the same order of magnitude. Probably it could not have been caused by ice attraction alone. It appears more likely to have been due to a very gentle uplift and tilting at the north following a lowering of the lake by a cutting down of the outlet. The outlet being at the north, this movement may have backed the water at the south up to or over the first beach. If due to deformation by some other cause these facts modify the estimated effect of ice attraction on the Maumee beaches south of Birmingham.

RELATION OF MAUMEE BEACHES TO MORAINES AND OUTLETS NEAR IMLAY, MICH.

So long as the Fort Wayne outlet remained continuously active the history of Lake Maumee was very simple. But when the oscillating ice front had retreated as far as northeastern Lapeer County, Mich., the relations began to be complicated. The first opening of an outlet near Imlay probably occurred on the retreat of the ice front immediately preceding the making of the Defiance moraine. Though no positive proof of such an opening is at present available, one is suggested by the character of the Defiance moraine where it passes from southwestern Almont Township into eastern Attica Township. It seems certain that an outlet past Imlay was opened at the retreat next preceding the Birmingham moraine, the low, slender character of this moraine from Romeo to Imlay being apparently due to the presence of this outlet river close along the ice front. (See pp. 283–284.)

From a point a mile or two southeast of Dryden the Defiance moraine begins to weaken and from the northwest corner of Almont Township northward about 4 miles to Belle River it shows the same kind of modification and weakening that characterizes the Birmingham moraine north of Romeo.

If an outlet was opened before the building of the Defiance moraine it was closed when the ice readvanced to that moraine. At the next backward oscillation a new outlet was opened through the same district and was in turn closed by the readvance to the Birmingham moraine. Nothing definite is known concerning the first of these outlets, but in all probability the Lum and Rochester channels are parts of the second one.

At the next back step of the ice front another outlet was opened, apparently at a somewhat lower level, and it was during the activity of this outlet that the lowest beach of Lake Maumee was made. The next step of readvance of the ice did not close the outlet but pushed it up the slope to the place where the Imlay outlet channel is now found, close in front of the Imlay moraine and 20 feet higher than the lowest beach. The location of the outlet channel at the time of the lowest beach is not definitely known. In southeastern Lapeer County and in Genesee County it appears to have been overridden and destroyed, but it was very probably followed by the Imlay outlet river from near North Branch to the narrows above Columbiaville. This may account for the apparent greater depth and later aggradation of this part of the Imlay channel.

Glacial Lake Lapeer, a small lake in central Lapeer County, existed during the building of the Defiance moraine. Silverwood glacial lake, in northern Lapeer County, appears to have been formed at the time of the Imlay or perhaps of the Goodland moraine. It stood at about 860 feet altitude near Silverwood and received the Silverwood and Fostoria outwash aprons. It may be that a closing of the outlet in Genesee County by the readvance to either the St. Johns or the Fowler moraine held it in place. Its relations and correlative moraines, however, are not definitely known.

During the remainder of the life of Lake Maumee, while the Goodland, Berville, Mount Clemens, Emmett, and Yale moraines were being made, the oscillations went on without affecting the level of the lake so far as known. Perhaps at the retreat following the Yale moraine a new outlet, through the East Dayton channel, may have been opened just before the final fall of the waters to a much lower level; but the relations and connections of this channel are also still problematic.

ICE BARRIERS OF LAKE MAUMEE.

In its earliest beginnings Lake Maumee was confined to a small area in Indiana and northwestern Ohio and its ice barrier was then the front of the Huron-Erie or Maumee ice lobe. The subordinate members of the Fort Wayne moraine are faintly developed between the main Fort Wayne and Defiance moraines, but there are several of them and they mark as many resting places of the ice barrier, each probably marking the culmination of a slight readvance. During the time of the Defiance and Birmingham moraines the Fort Wayne outlet was still active and the relation of the ice barrier to the lake continued to be extremely simple. But when the oscillations opened outlets on the "thumb" and closed them by readvances the level of the lake was probably affected by nearly every movement of the ice front.

Until the ice had retreated about to the Mount Clemens moraine the ice barrier presented a single lobate front, for the Huron and Erie ice lobes were probably still welded together along their line of contact in southwestern Ontario. The crease between them, however, had become accentuated. Ontario Island,[1] which had probably begun to be uncovered at the time of the Defiance moraine, had now become much enlarged and the ice lobes were on the point of complete and final separation. The position of the moraines in Michigan and southwestern Ontario seems to indicate that the separation occurred just after the building of the Mount Clemens moraine.

During the closing stages of Lake Maumee the ice front stood on the Yale moraine or possibly somewhat farther north, and the correlative of this in the Lake Erie basin is probably found in one of the moraines immediately preceding the Gowanda moraine of western New York. This is in harmony with the correlation of certain gravel deposits at Girard and Fairview, Pa., with the lowest beach of Lake Maumee, and it is also in harmony with the very clear correlation of the Alden moraine of western New York with a late substage of the Port Huron morainic system of Michigan. Three positions of the western barrier of Lake Maumee are shown in figure 6 (p. 370).

At its close, therefore, Lake Maumee, like all the later Huron-Erie glacial lakes, was retained by two separated ice barriers, one in the Huron basin and the other in the Erie basin. At this time Lake Maumee had a short stretch of northern land shore in the vicinity of London, Ontario. The length of this, however, could not have been great, and it endured for only a relatively short time before the lake waters fell to a lower level. A faint shore line marking this last stage of Lake Maumee may be looked for in the vicinity of London, though none has yet been reported.

CORRELATIVES OF LAKE MAUMEE.

As nearly as can be determined by a study of correlative moraines in the different lake basins, it seems almost certain that Lake Chicago had its early beginnings at about the same time as Lake Maumee, but such evidence as is now available indicates that Lake Duluth, in the western end of the Lake Superior basin, began later. Toward the close of the existence of Lake Maumee Lake Saginaw was formed in front of the Saginaw lobe. It received the overflow of Lake Maumee but did not attain large size at this time.

As the waters fell to the level of the Arkona beaches a transient precursor of Lake Whittlesey must have been formed, but its duration was probably very brief.

[1] The uncovering of Ontario Island is described by the writer in The moraine systems of southwestern Ontario: Trans. Canadian Inst., vol. 10, 1913, pp. 37-39, with map.

CHAPTER XIV.

GLACIAL LAKE CHICAGO.

By Frank Leverett.

EARLY INVESTIGATIONS.

The beaches of glacial Lake Chicago from the outlet near Chicago northward to the Illinois-Wisconsin line on the west side of Lake Michigan and to the vicinity of Holland, Mich., on the east side, have already been described by the writer.[1] More recently studies by the writer and by Mr. Taylor have been extended northward on the east side of the lake to the Straits of Mackinac, and studies by Alden and by Goldthwait have covered much of the Wisconsin part of the west side of the basin, Alden devoting himself chiefly to the Chicago beaches, and Goldthwait to the Algonquin and Nipissing beaches.

DISTRIBUTION OF BEACHES.

As a result of these studies it has been determined that the two higher beaches of Lake Chicago, the Glenwood and the Calumet, are not present in the northern part of the Lake Michigan basin, at least as surface features. A readvance of ice has probably to some extent overridden and buried their northern ends, making it impossible to determine their full limits. On the east shore they are traceable to a gravel plain outside the Manistee moraine that passes beneath Lake Michigan between Ludington and Manistee and that appears to be a part of the Port Huron morainic system of the Huron basin. On the west shore traces of stream deltas and a slight beach at about 60 feet were found by Alden to extend northward to a point 10 or 12 miles south of Manitowoc.

GLENWOOD BEACH.

GENERAL DISTRIBUTION.

The Glenwood beach, named from Glenwood, Ill., a village standing on it a few miles south of Chicago, is the highest beach formed by Lake Chicago. In the Wisconsin portion it lies very close to the shore of Lake Michigan; in fact it has been to some extent cut away by the encroachments of the modern lake and to still greater extent by the encroachments of Lakes Nipissing and Algonquin. In the Illinois portion it has been cut away by the modern lake for a few miles between Waukegan and Winnetka and lies near the Lake Michigan shore north of Waukegan. From Winnetka southward the beach passes inland a few miles and remains some distance back from the shore of Lake Michigan as far east as the vicinity of Chesterton, Ind. From near Chesterton northward into Michigan as far as Holland it lies along the west slope of Covert Ridge, the till ridge of the Lake Border morainic system nearest the lake. In few places is it more than 2 miles from the shore of the modern lake, and in some places it has been cut back by the modern lake. From Holland northward past the Grand and Muskegon valleys it lies 6 to 20 miles back from the Lake Michigan shore, being most distant south of Grand River valley. About 10 miles north of the mouth of Muskegon River the beach comes back to the shore of Lake Michigan. From that point northward past Little Point Sable it has been largely cut away by the encroachments of Lake Michigan. In the vicinity of Pentwater it lies back several miles from the Lake Michigan shore, but has been cut away for a few miles south of Ludington. Near Ludington and northward to the gravel plain and moraine that override it, it lies back several miles from the shore.

[1] Mon. U. S. Geol. Survey, vol. 38, 1899, pp. 427-453.

SOUTH END OF BASIN.

The altitude of the beach at the southern end of the Lake Michigan basin, as found by Goldthwait's levels in Cook and Lake counties, Ill., and Kenosha County, Wis., is not over 638 feet above sea level and was determined apparently by the level of the Chicago outlet at the time it was forming. The Glenwood beach in the Chicago district and northward to Racine is in places split up into three or more distinct crests, and it is probable that the outlet was lowered slightly during the development of the beach.

In the Illinois part of the Glenwood beach cut banks are more common than ridges of gravel or sand thrown up by the waves. The gravel ridges are chiefly at embayments where bars were projected out into the water by currents working along the shore. But from Waukegan north to Racine a gravel ridge prevails, as noted by Goldthwait. From Glenwood eastward about to Chesterton, Ind., deposits of gravel and sand are conspicuous and the beach is in places composed of a series of parallel ridges separated by narrow sags. Where sandy and subject to wind action the beach is thrown up to a height of 25 or 30 feet, but where gravelly it in few places rises 10 feet above the bordering plains. The ridges are somewhat disjointed and have a tendency to overlap.

The shallow waters of the lake apparently extended in places into bays or up valleys in which the wave action was insufficient to develop the beach thoroughly. From one of these extensions in Deep River valley near Hobart the water perhaps extended along Turkey Creek to the main beach a few miles west of Hobart. A bay in Salt Creek valley extended 3 or 4 miles south of the main beach, and still another extended up Calumet Valley about to the east line of Porter County, Ind. Much of the area covered by this last bay is thinly coated with sand. East of Hobart the sand is slightly ridged, but generally it is flat surfaced.

A bay also occupied East and West Trail Creek valleys on the southeast or outer border of a till ridge of the Lake Border morainic system, connecting with Lake Chicago through a gap in the till ridge now utilized by Trail Creek below the junction of the two forks. Another bay occupied the lower courses of the forks of Galien River in southern Berrien County, Mich., back of the Covert till ridge. This bay and the one in the Trail Creek drainage basin stand in the line of drainage of the small glacial lake that occupied the lower course of the St. Joseph and Paw Paw valleys and discharged southwestward to the incipient Lake Chicago at Chesterton (pp. 226–227). Deposits of sand several feet deep along the line of these pools may be in part the deposit of this drainage, and thus antedate the Glenwood beach. The small lake in the St. Joseph and Paw Paw valleys stood somewhat higher than the Glenwood beach and probably each of the pools through which it discharged was a little above the level of that beach, for they were too low to be connected by a stream but opened severally through gaps in the till ridge to the west to Lake Chicago.

Another small bay near the confluence of Paw Paw and St. Joseph rivers opened into Lake Chicago at the present mouth of St. Joseph River. The portion of the Covert till ridge immediately south of St. Joseph was nearly submerged, so that the waters of Lake Chicago may have rolled over it into the bay back of the ridge. The portion of the till ridge north of St. Joseph River rose considerably above the level of the lake and bay.

Still another bay lay back of Covert till ridge at the junction of the several forks of Black River east of South Haven, and opened into the lake near the site of that city. The lake rolled over the crest of the Covert till ridge into this bay for a short distance in the vicinity of South Haven. A definite beach was found east of the bay for 4 or 5 miles south of Kibbe station.

At Kalamazoo Valley the till ridge runs back from the shore of Lake Michigan to New Richmond, causing a sharp embayment in Lake Chicago itself west of the ridge. The submergence extended east of the ridge but covered an area very much smaller than that of the glacial lake that covered the same region while the ridge was in process of formation, the water standing 35 or 40 feet lower than at the earlier stage.

EAST SIDE OF BASIN.

The Glenwood beach from northern Indiana northward to Holland, Mich., is rather sandy as a whole, though gravelly in numerous places. Cut banks are very uncommon. The gravelly portions of the beach are the most definite and easiest to follow, for the sandy ones are liable to be confused by sand drifting to higher altitudes. A most conspicuous sand ridge, lying above the Glenwood beach a few miles south of St. Joseph, in the vicinity of Bridgman, follows the crest of the Covert till ridge for a few miles and then passes down the outer slope and runs some distance on the plain at its back. Its continuity is remarkable, especially since it lies in places a mile or more east of the beach. That it was formed not by water but by wind is clear from the fact that it reaches in places an altitude 50 or 60 feet higher than the Glenwood beach and has a range of fully 60 feet in altitude.

Immediately south and east of Holland the Glenwood beach has exceptional strength, shore deposits 25 feet or more in depth being banked against the inner or northwest slope of the Covert till ridge. The beach is a sandy gravel which becomes in places nearly clear sand. At the northeast this beach connects with a large delta formed by one of the distributary channels of the Grand River outlet, which separates from the present course of Grand River just below Grand Rapids. Its delta covers 2 or 3 square miles in the vicinity of Zeeland and fills in the space between two till ridges which lead northward from the old outlet. The gravel, which is 25 feet or more in depth, is somewhat coarser than that of the beach south of Holland. It was cut into and much of it removed by the Grand River outlet at a later and lower stage of Lake Chicago, but its original level is preserved not only on the borders of the channel but in island-like remnants in the midst of the channel.

North of this delta Lake Chicago washed against the west side of the western till ridge, but it deposited very little gravel, and the limits of the lake are not clear at all points. From the northern end of this till ridge near Crisp the lake extended eastward about 10 miles across Blendon into the edge of Georgetown Township, Ottawa County, to the eastern of the two till ridges. On the western slope of the till ridge a somewhat definite gravelly beach connects at the north with a large delta formed by the northern branch of the Grand River outlet.

The delta of the northern branch of the Grand River outlet lies mainly in Allendale Township, Ottawa County, covering an area of about 30 square miles, roughly bounded by the eastern till ridge on the southeast, by Bass River on the south and west, and by Grand River on the north. The material is a fine gravel and its depth is 15 to 30 feet. The delta has been trenched in its northern portion by the Grand River outlet, which has formed channels about 25 feet in depth and nearly a half mile in width which run entirely across the delta. This trenching is an adjustment of the bed of the channel to a lower stage of Lake Chicago than that marked by the Glenwood beach.

North of Grand River the Glenwood beach sets in at Eastmanville and runs northward along the western slope of the western till ridge, passing about a half mile east and north of Dennison and coming to the valley of Crockery Creek at the line of Muskegon and Ottawa counties. This portion of the beach is sandy and the precise level of the lake is in places difficult to determine.

In the sandy district that extends from Crockery Creek northward past Muskegon River the limits of the lake are not easy to determine. The most definite line which the present writer was able to follow lies along the eastern edge of a swampy tract about a mile west of the crest of the western till ridge in secs. 20, 17, and 8, Ravenna Township. From sec. 8 the swamp border bears westward across the south edge of sec. 6 and the northeast corner of Sullivan Township to the western end of the west arm of the till ridge in the south part of sec. 35, Eggleston Township, about 10 miles east of the main part of Muskegon. Farther north no definite line was discovered, though the surface is a little more broken by ridges and ravines east of a line passing from the west end of this till ridge to Wolf Lake in sec. 16, Eggleston Township, than it is west of that line, and this change in topography may mark the lake border. Some uncertainty, however, arises from the apparently higher altitude of the division line.

The Grand Trunk Railway survey indicates that the border of the swamp in western Ravenna Township is about 660 feet above sea level, and a series of levels run by Goldthwait at Eastmanville, only 15 miles south, indicate that the strongest beach there is but 632 feet. Faint indications of shore action appear on the moraine north of Eastmanville in the southeast part of sec. 29 at about 654 feet, and ridges northeast of Dennison by Goldthwait's levels rise to 655 and 665 feet. The highest of these, at a gravel pit at Amos Taylor's farm, is strong and seems to have been shaped by waves, yet its lack of continuity may be an indication that it is not a shore feature. Before this correlation can be satisfactorily settled and the 660-foot beach classed as Glenwood further studies should be made and levels run to determine whether a lower shore exists at a level corresponding with the general elevation of the beach in the southern end of the Lake Michigan basin, or about 640 feet. It may be remarked, however, that all the observations on the beach north of Muskegon indicate that its altitude is about 660 feet and that it is thus in harmony with the line which follows the east border of the swamp in Ravenna and Sullivan townships, Muskegon County, and with Goldthwait's levels near Dennison.

North of Muskegon River the Glenwood beach lies along the west side of the Whitehall till ridge from sec. 23, Fruitland Township, northward, the ridge itself rising nearly to the level of this beach in the northeast part of sec. 36. The district east of the till ridge was probably submerged at this time no farther north than the vicinity of Sweet station, for basins are present in the gravelly plain north of that station.

On the north side of White River a narrow till plain lying along the inner slope of Whitehall till ridge stands slightly above the level of Lake Chicago. A ridge of sandy gravel, apparently marking the shore, leads westward from the Whitehall till ridge near the north edge of Montague through the north part of sec. 20 and south part of sec. 18, Montague Township, and the north part of sec. 13, White River Township, to another till ridge in sec. 14. This shore has an altitude of 655 feet immediately north of Montague, as determined by Goldthwait's levels, or about 5 feet lower than the supposed shore crossed by the Grand Trunk Railway east of Muskegon in western Ravenna Township.

Shore features are poorly developed on the west slope of the till ridge in White River Township, the surface being very irregular. From near the line of Muskegon and Oceana counties northward for several miles the bluff of the modern lake rises above the level of the Glenwood beach, some points being fully 200 feet above Lake Michigan. At Benona, where Stony Creek enters the modern lake, a recess of Lake Chicago extended inland about 3 miles, covering the southern edge of secs. 31, 32, 33, Benona Township, and the northwestern part of Claybank Township. The upper limits of lake action are 75 to 80 feet above Lake Michigan, 655 to 660 feet above sea level. For several miles north of this recess the shore of Lake Michigan is again very prominent. Near Silver Lake a recess extends into secs. 16, 21, 28, and 33, Golden Township, and north of this the Glenwood beach comes back to the shore of Lake Michigan in sec. 8. Hand levels run near the line of secs. 5 and 8 show its altitude to be 75 feet above Lake Michigan at a 582-foot stage, or 657 feet above sea level.

In northwestern Oceana County the Glenwood beach runs back inland nearly to Hart. A terrace on Pentwater River at Hart, altitude 655 feet, probably marks the level of the stream bed. On the north side of Pentwater River just below the junction of the two forks, immediately east of Pentwater, a till ridge sets in which stands at about the level of the Glenwood beach for several miles northward and which has its crest generally capped with sand. A bay east of this till ridge apparently covered about 25 square miles of sandy plain in northwestern Oceana and southwestern Mason counties, though its limits are difficult to define.

About 3 miles north of the Oceana-Mason county line the Glenwood beach comes back to the shore of Lake Michigan at an altitude, by Goldthwait's levels, of 649 to 650 feet. For 4 miles north from this point high bluffs mark the coming of a prominent moraine to the lake shore. North of this moraine on the south bluff of Pere Marquette River lake action was found to be well defined at about 660 to 665 feet. The shore from there runs eastward along the south side of Pere Marquette River nearly to Scottville and then goes northwestward, passing just

south and west of Amber to the bluff of Lincoln River near Victory; Goldthwait's levels around Amber make its altitude 673 to 675 feet. The portion between Amber and Victory is characterized by definite ridges of sand following the border between a sandy plain and a morainic ridge. North of Lincoln River the sandy ridges are more disjointed than between Amber and Victory. The shore apparently follows the inner edge of the moraine northwestward from Lincoln River to Sable River at the head of Hamlin or Sable Lake. It then runs up the south side of Sable River to the edge of Freesoil Township, a short distance west of the village of Freesoil, where it passes to the north side of the river and leads northwestward along the northern edge of a swampy plain. North of this swampy plain lies a pitted gravel plain formed apparently as an outwash from the moraine to the north. Between sec. 10, Grant Township, and the shore of Lake Michigan a sandy tract, which has been modified more or less by wind action, but which may have been covered by Lake Chicago, lies immediately south of the moraine which comes out to the shore of Lake Michigan just south of the line of Manistee and Mason counties. As already indicated, the Glenwood beach has not been found north of this moraine. (See p. 309.)

WEST SIDE OF BASIN.

Investigations on the western shore of Lake Michigan have brought to light no evidence that the Glenwood beach there has suffered any uplift. On the eastern shore, as already noted, the beach apparently stands a few feet higher in the portion north of the latitude of Muskegon than in the southern end of the basin. More detailed work and some spirit leveling seem necessary to clear up the nature of the uplift or warping of the beach in that region.

CALUMET BEACH.

GENERAL FEATURES.

The Calumet beach, like the Glenwood, opens into the Chicago outlet, but stands 20 or 25 feet below the level of the Glenwood beach, its altitude above Lake Michigan at the southern end of the Lake Michigan basin being about 35 feet. The question of a lower lake level having come in between the Glenwood and Calumet beaches is considered later (p. 356).

Along much of the shore of Lake Michigan, both on the Michigan and the Wisconsin-Illinois side, this beach has been cut away, and it nowhere lies more than 12 miles back from the shore of Lake Michigan. It is best preserved along the south side of Calumet River in northwestern Indiana, and for this reason has been given the name Calumet beach. It lies from 1 to 8 miles back from the present shore of Lake Michigan from near the Michigan-Indiana State line westward across the Indiana portion of the shore and northward about to Winnetka, Ill.[1]

DISTRIBUTION IN MICHIGAN.

In Michigan it appears on the bluff of Lake Michigan for a few miles between New Buffalo and St. Joseph but is absent from St. Joseph northward nearly to South Haven. A short section is preserved near the mouth of Black River at South Haven. It is also preserved for a short distance on the south side of the mouth of the Kalamazoo at Saugatuck and at intervals from there to Black Lake. It follows the south side of Black Lake from the Lake Michigan shore eastward through Holland and then goes northward, coming to Grand River near the mouth of Bass River, its distance back from the lake in this interval being 6 to 12 miles or as great as on any part of the shore. North of Grand River it goes northwestward to Fruitport and thence westward to the shore of Lake Michigan at Lake Harbor. It follows the lake shore to Muskegon Lake and then runs back eastward through Muskegon, being well defined near the high school and other points in the city. It is difficult to determine the extent of the lake up the Muskegon Valley, for eastward from Muskegon it was a mere estuary less than 2 miles in width. North of Muskegon River the beach follows the bluff of the river and of Muskegon Lake nearly to the shore of Lake Michigan and reaches the shore only 2 or 3 miles north of the point where

[1] Mon. U. S. Geol. Survey, vol. 38, 1899, pp. 442-446; Chicago folio (No. 81), Geol. Atlas U. S., U. S. Geol. Survey, 1902, pp. 9-10, map p. 11; Prof. Paper U. S. Geol. Survey No. 34, 1905, pp. 71-72; Pl. XIV (map).

Muskegon Lake opens into Lake Michigan. It follows the shore pretty closely to White Lake and extends up the border of that lake about to Whitehall. It is present on the north shore of White Lake from Montague down to the point where the lake opens into Lake Michigan. Thence northward past Little Point Au Sable the beach is cut away except for a mile or so at the mouth of Silver Creek near Benona. North of Little Point Au Sable the beach extends eastward along the south shore of Silver Lake and returns northwestward along the north shore to Lake Michigan, keeping a mile or so inside the limits of the Glenwood beach. The beach is then cut away for a short distance in northwestern Golden Township, Oceana County, but runs eastward through southern Pentwater Township to the head of Pentwater Lake. It then runs northward through the eastern part of Pentwater and follows the western slope of a till ridge northward into Mason County, passing east of Bass Lake and coming back to the shore of Lake Michigan immediately north of the shore of Bass Lake. It is then cut away northward as far as the mouth of Pere Marquette River but reappears in the eastern part of Ludington between Pere Marquette and Lincoln rivers and continues northward along the east side of Big Sable Lake to the head of the lake. It then runs northward to the shore of Lake Michigan in southwestern Grant Township. Farther north no traces of it have been found and it appears to have been overridden by the moraine that comes out to the Lake Michigan shore in the northwestern corner of Mason County.

STRUCTURE.

In general the Calumet beach is gravelly, though in places it becomes rather sandy. Immediately east of Bass Lake in southwestern Mason County a series of parallel ridges, which give it unusual strength, appear to have been built across the mouth of a bay that there extended eastward through a gap in the till ridge. At Ludington the beach is rather disjointed and fragmentary, though at certain points, as at the crossing of Ludington and Washington avenues, it is clearly defined. Its poor preservation makes it difficult to estimate its general strength, but it seems on the whole to be about as strong in its northern part as it is near the outlet, where its strength compares favorably with that of the Glenwood beach and indicates a lake stage of considerable duration. The Calumet appears throughout its course as a single ridge and a strong one.

TOPOGRAPHY.

The Calumet beach, like the Glenwood, is somewhat higher for a short distance in the northern portion of the eastern shore than it is in the southern end of the Lake Michigan basin. Spirit levels run at Ludington by J. A. Mitchell, county surveyor, show the crest of the beach, at the crossing of Ludington Avenue near Washington Avenue, to be 636 feet above sea level or about 56 feet above Lake Michigan. The strong beaches near Bass Lake were found by Goldthwait to be 46 to 48 feet above Lake Michigan or 627 to 629 feet above sea level, and a weaker ridge between these strong ones and the lake is 38 feet above the lake or 619 feet above sea level. The altitude at Muskegon is about 46 feet above the lake as determined by Goldthwait, or 627 feet above sea level. In Muskegon there are indications of shore action at 33 to 35 feet above the lake. The remainder of the shore to the south seems to be but 35 to 40 feet above the lake or 615 to 620 feet above sea level.

Reference was made in the discussion of the Glenwood beach to channels cut across the large deltas formed by the Grand River outlet near Zeeland and in Allendale Township, Ottawa County. These channels appear to be in harmony with the Calumet beach, their floors being within about 5 feet of the level of that beach. The channels on the Allendale delta are apparently as high as the Calumet beach, but the one in the delta at Zeeland seems to be a few feet lower. The channel that leads to Zeeland is, however, filled by peaty accumulations a short distance above Zeeland to a level fully as high as the Calumet beach, and it nowhere seems low enough to be in harmony with the next lower or Toleston beach.

PEATY DEPOSITS.

Deposits of peaty material found under portions of the Calumet beach have been interpreted to signify that the lake level stood lower than the Calumet beach at a time prior to the development of that beach. A conspicuous burial of peat under the gravel of the Calumet stage of the lake is found in Evanston, Ill., where the gravel extended southward as a bar into a bay that stood back of the present city. A recent exposure of peat below the Calumet beach at Bowmanville is noted by F. C. Baker.[1] However, although the presence of peat under the gravel suggests a lower stage of water it can scarcely be said to prove it conclusively, for a bar might be extended out over a peaty deposit standing at the same level as the lake and might press it down and thus give it a lower level than it had while in process of growth. At the Evanston locality this interpretation would seem very plausible, for the bar was built out into water of considerable depth by southward-moving currents. Other peaty deposits are extensively covered by the gravels of the Calumet beach along the bluff of Lake Michigan between Michigan City, Ind., and New Buffalo, Mich. In this place there seems to have been no bar, but a regular beach. The peat ranges from about 15 feet above the lake down to the water's edge. The layers, few of which are more than 6 inches thick, are interbedded with sand. One layer standing 12 to 15 feet above the lake is traceable continuously for fully half a mile along the shore about 2 miles southwest of New Buffalo. Near Michigan City the peaty layers are continuous just above the water's edge for a mile or more. Pebbly sand above the peaty beds in places reaches an elevation of 30 feet or more above the lake or nearly to the level of the Calumet beach. The sand evidently was deposited during the development of that beach and the peat is certainly as old as the beach. The beach may have been extended out over a peaty deposit, as was suggested in the case of the Evanston deposits, but the conditions on the whole do not strongly favor this view. If a lower lake level preceded the development of the Calumet beach other evidence than that from the buried peat deposits should be found. For instance, the valleys which entered the lake at this lower stage should have been cut to a level below the Calumet beach and then the beach should have been built across the beds of these channels as the Whittlesey beach was across the valleys that were cut to the level of Lake Arkona in eastern Michigan.

TOLESTON BEACH.

DISTRIBUTION.

A third beach of Lake Chicago which was barely high enough to open into the Chicago outlet has received the name Toleston from a village situated on it in northwestern Indiana (now absorbed by the city of Gary). The beach, which lies 18 to 25 feet above the level of Lake Michigan, is preserved in much of the Indiana portion and in the Illinois portion as far north as Evanston, but is generally cut away on both shores of Lake Michigan north of a line running from Evanston, Ill., to Michigan City, Ind.

The Toleston beach appeared to be present at Holland, Mich., at the eastern end of Black Lake, being built out between the lake and the marsh which extends east from Holland a short distance. It is there built up to a height of 21 to 22.5 feet above Lake Michigan, as shown by Goldthwait's levels. From Holland it seems likely to have continued northward to Grand River, but as that region is extensively covered with sand blown from the modern shore the beach is largely concealed. In Springport Goldthwait's levels show the beach to be about 21 feet above Lake Michigan. From Grand River it appears to run northwestward, passing just east of Little Black Lake on the line of Muskegon and Ottawa counties and coming to the shore of Lake Michigan directly west of the north end of the lake. There is probably no point between Holland and Grand River where its distance from the present shore exceeds 6 miles, and throughout much of the distance it probably does not exceed 2 or 3 miles.

The beach has very little development in the recesses of the shore in Muskegon, Oceana, and Mason counties and so far as developed appears to be not more than 25 feet above the level of Lake Michigan.

[1] Science, new ser., vol. 31, 1910, p. 715.

CORRELATION.

The Toleston beach may have been only partly formed by Lake Chicago. It has a level that was closely approximated if not reached by Lake Algonquin. The occurrence of a lake at this level in Algonquin time makes this beach a part of the Algonquin beach of the upper Great Lakes region.

The Algonquin beach carries in a few places molluscan shells, and this beach of Lake Chicago is in places richly supplied with these shells. In this respect it contrasts with the Calumet and Glenwood beaches, from which molluscan remains have as yet been reported at but one locality, near Bowmanville, north of Chicago.[1] Sea shells found by Alden and an oyster shell found by the writer may have been brought in by human agencies. Although Lake Algonquin did have two outlets (past Chicago and Port Huron), sufficient reason for its later complete discharge by Port Huron is found in the fact that the latter outlet was through easily eroded drift deposits and the Chicago outlet was over a rock sill.

BEACHES LOWER THAN THE TOLESTON.

Numerous ridges in the southern portion of the Lake Michigan basin at levels a little below that of the Toleston beach probably belong, the higher to Lake Algonquin and the lower to Lake Nipissing. Most of them rise 10 to 15 feet above Lake Michigan, or about 595 feet above sea level, but some reach about 600 feet and others not more than 590 feet. The Chicago outlet seems to have ceased to be functional at the time they were developed, for they in a measure choke up or bridge over its head. Furthermore, they are about as low as the bed of the outlet, so that no depth of water would have been possible along the outlet. These ridges are exceptionally well displayed in the south part of Chicago in the vicinity of the university, and they are even better developed just east of the Illinois-Indiana State line. On a line running north from Gibson station there are by actual count 32 beachlets separated by shallow sags.

North of Waukegon a cut bank appears at a level corresponding to that of the beaches in the southern end of the lake basin, its base being 12 to 15 feet above Lake Michigan level. Chamberlin[2] made reference to this, and Alden[3] mentions and pictures a fragment of it. On the Michigan shore east of Bass Lake in Mason County a cut bank was noted whose level at base is about 12 feet above Lake Michigan. Slight indications of wave action at a level about 12 feet above Lake Michigan are found at several other points in recesses along the Michigan shore.

SAND DUNES.

Attention has been directed to sand ridges and low dunes that are apparently connected with the Glenwood beach. They are, however, inconspicuous compared with the dunes that lie along the modern shore. Wherever the beach is sandy, dunes are in process of formation, from the head of the lake in northwestern Indiana along the entire eastern shore of Lake Michigan to the Straits of Mackinac. The longest uninterrupted stretches are between the mouths of Kalamazoo and White rivers in Michigan and from the vicinity of St. Joseph, Mich., southwestward past Michigan City, Ind., to the head of the lake. Very prominent dunes occupy much of the interval between Ludington and Manistee, and a prominent dune belt about 15 miles long in northwestern Oceana and southwestern Mason counties extends several miles each way from Pentwater. Many of the dunes reach an altitude of 150 feet and in a few places exceed 200 feet. The highest are confined to a belt scarcely a mile in width, but lower ones appear for several miles back of these, in the sandy area between Holland and Muskegon and in that west from Michigan City, Ind.

Dunes are lacking chiefly at points where the lake is encroaching on morainic ridges, as on those of the Lake Border morainic system in the southern end of the basin.

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[1] Baker, F. C., Science, new ser., vol. 31, 1910, p. 715.
[2] Geology of Wisconsin, 1873-1877, vol. 2, pp. 227-228.
[3] Alden, W. C., Milwaukee folio (No. 140), Geol. Atlas U. S., U. S. Geol. Survey, 1906, p. 9.

CHAPTER XV.

GLACIAL LAKE SAGINAW.

By Frank B. Taylor.

HISTORY OF THE LAKE.

OUTLINE OF HISTORY.

Glacial Lake Saginaw occupied the Saginaw basin, and in its first period was an independent contemporary of the later stages of Lake Maumee. After being a western extension of Lake Arkona it had another period of independent existence during the time of Lake Whittlesey. Later, it was again merged with the greater waters east of the "thumb," first with Lake Wayne, which discharged eastward past Syracuse, N. Y., and later with Lake Warren, which discharged westward. Still later, it formed part of Lake Lundy, which again discharged eastward past Syracuse.

While Lake Saginaw was independent and while it was merged with Lakes Arkona and Warren, its outlet was westward through the Grand River channel. At other times its outlet was eastward past Syracuse.

EARLY LAKE SAGINAW.

The earliest beginnings of Lake Saginaw were just after the building of the Flint moraine and the making of the early western part of the Imlay channel (from Flint to Maple Rapids). The lake was scarcely more than a pond in its earliest stages, and began to be large enough to make a beach by wave action only after the ice had retreated from the Henderson moraine.

Between Elsie and Duplain and eastward from Elsie to Flushing a very faint fragmentary shore line—in places a faint lake cliff, but more commonly a narrow, low ridge of gravel—lies 10 to 15 feet [1] above the much stronger Arkona ridges and 720 to 725 feet (aneroid) above sea level. This is called the Duplain beach, or the first beach of Lake Saginaw. It is very immature, for it follows all the sinuosities of the ground like a contour line. When it was abandoned the lake had accomplished extremely little toward straightening its shore. Only two or three fragments of this beach were observed north of Grand River, and its limits are not yet known.

With continued recession of the ice front, the lake expanded in size until it merged with Lake Arkona. For a time it was a rather long, narrow, crescent-shaped lake reaching northward between the ice and the land about as far as it did eastward. Before it widened out and approached its greatest extent as an independent lake it seems probable that its outlet had been cut down so that its shore line was as low as the level of the highest Arkona beach. Although such a beach has not been observed as an independent form, it seems certain that it must have existed and that it was the second beach of Lake Saginaw.

LAKES SAGINAW AND ARKONA.

When the ice barrier withdrew from the "thumb," a strait was opened across its northern low part and the waters on both sides merged at one level, making Lake Arkona and adding to it the area of Lake Saginaw. In this change Lake Saginaw, with its undisturbed outlet, became the controlling factor. The new lake became merely a greatly enlarged Lake Saginaw, the conditions of the latter lake and its outlet remaining unchanged. At this time the Arkona beaches began to be formed and the first one probably merged with the preexisting second beach of Lake Saginaw to form one continuous shore. The only change was that greater waves now

[1] This beach was called the Duplain beach in an earlier publication, entitled Correlation of Erie-Huron beaches with outlets and moraines in southeastern Michigan: Bull. Geol. Soc. America, vol. 8, 1896, pp. 53–54.

beat upon the shores of Lake Saginaw than before, and the second Saginaw beach (made by the independent lake) was completely overwhelmed and worked over into the new, stronger, first beach of Lake Arkona.

In this way the first Arkona beach was apparently superposed upon the second beach of Lake Saginaw, and what now stands as the highest strong beach in the Saginaw basin is more characteristic of Lake Arkona than of Lake Saginaw.

But Lake Saginaw made other beaches before it ceased to exist. In the western part of the valley there is another Arkona ridge 10 feet or less below the upper, and the lower one is generally the stronger of the two. Northeastward from Flushing a third beach gradually separates below the other two and is fairly strong toward Cass City. These three beaches must have been made by Lake Arkona before the time of Lake Whittlesey, because they all occur on the east side of the "thumb" and were modified by submergence under the latter lake. For descriptive details of the Arkona beaches see pages 362–375.

SECOND LAKE SAGINAW.

When the ice front readvanced from its position as the barrier of Lake Arkona it closed the strait around the "thumb" and raised the waters east of it about 44 feet, thus inaugurating Lake Whittlesey. The change, however, caused no notable alteration in the discharge from Lake Saginaw, because from its beginning to the time of Lake Arkona Lake Maumee discharged into it, and after Lake Arkona ceased Lake Whittlesey discharged into it. Hence, the volume of water passing out of Lake Saginaw was not affected by the changes.

During the time of Lake Whittlesey, therefore, Lake Saginaw had a second period of independent existence with its area almost at a maximum. It seems certain that the lower Arkona ridge of the Saginaw basin was made chiefly by the waves of Lake Arkona, and it seems equally sure that during the time of Lake Whittlesey the waves of Lake Saginaw beat upon this same beach, although nothing clearly establishing this relation has been observed. In the absence of positive evidence one way or the other, these inferences seem natural and necessary.

LAKES SAGINAW AND WAYNE.

When the waters fell from Lake Whittlesey they were lowered about 80 feet, not to the Warren beach, as one might suppose, but to the Wayne beach and perhaps later to a lower level. The Wayne beach lies about 20 feet below the Warren and shows modification by submergence after it was made, in this respect resembling the Arkona beaches. There is much reason for thinking that this lake fell to still lower levels before its end. No proof of this has been found, but its outlet was near Syracuse, N. Y., where the situation favored large changes of lake level with relatively small oscillations of the ice front. While Lake Saginaw formed a part of Lake Wayne it abandoned the Grand River channel, its water standing a little below the head of that outlet. The Wayne beach is described on pages 386–391.

LAKES SAGINAW AND WARREN.

When the ice barrier readvanced from its position for Lake Wayne, it raised the water to the level of the Warren beach, the outlet was again restored to the Grand River channel, and conditions much like those of Lake Arkona prevailed. This change inaugurated Lake Warren, with its shore line 25 or 30 feet below the lowest of the strong Arkona ridges. For a description of the Warren beach see pages 392–398.

LAKES SAGINAW AND LUNDY (LAKE DANA, LAKE ELKTON).

At the beginning of Lake Lundy, which followed Lake Warren, the Grand River outlet was again abandoned, this time finally, for the waters of the Saginaw basin merged with those of Lake Lundy, which drained through an outlet near Syracuse, N. Y. With the fall of Lake Lundy Lake Saginaw may be said to have come to an end.

It is thus seen that Lake Saginaw, though of relatively small area in itself, had a very complicated history and was intimately connected with the development and history of Lakes

Maumee, Arkona, Whittlesey, Wayne, Warren, and Lundy. In its relations to these lakes it illustrates in a wonderful way the vicissitudes of lake waters controlled by an ice sheet with periodic oscillations of front during retreat. The Lundy beach is described on pages 400–406.

ICE BARRIERS OF LAKE SAGINAW.

The first appearance of Lake Saginaw was probably during the back-step halt immediately preceding the building of the Owosso moraine, or possibly during the back step next following. (See p. 243 and fig. 1, p. 258.) This first stage and all the succeeding independent stages of Lake Saginaw were contemporaries or time equivalents of the later stages of Lake Maumee and of Lake Whittlesey. The ice lobe that formed the successive barriers of Lakes Maumee and Whittlesey in the Huron-Erie lowland extended also to the Saginaw Valley and formed barriers for Lake Saginaw. Several positions of the barriers are shown diagrammatically in figure 6 (p. 370). Considerable parts of these barriers are represented by moraines which have been studied and mapped. The barriers of the remaining stages when Lake Saginaw was merged with the Huron-Erie waters to the east (Lake Arkona and its successors down to Early Lake Algonquin) are also shown conjecturally in figure 6.

GRAND RIVER CHANNEL.

HISTORY.

The Grand River channel was the outlet of Lake Saginaw throughout most of the lake's history, even through part of the time when it was merged with the much larger glacial lakes of the Huron-Erie basin. A descriptive account of it, with some account of its early drainage and earlier development, has already been given. (See pp. 255–260.) Its later development, during its long service as a great outlet river, is discussed below.

The Grand River channel was in use a much longer time than any other channel in Michigan. It began to carry the lake waters when the outlet of Lake Maumee first opened near Imlay, before the beginning of Lake Saginaw. Later it received the discharge from Lake Maumee through the first Lake Saginaw. Next it received the overflow of the merged Lakes Arkona and Saginaw. Later, when by a readvance of the ice Lake Saginaw was restored to independent existence, it received the waters of Lakes Whittlesey and Saginaw. Only when the ice retreated from the Port Huron morainic system and Lake Saginaw merged again eastward and became part of Lake Wayne was the Grand River channel for the first time in its existence temporarily abandoned, the waters of the merged lakes draining eastward to the vicinity of Syracuse, N. Y. Through all previous changes, apparently without break or intermission from the first opening of the Imlay outlet, it had carried the overflow.

Later the ice readvanced, closing the eastern outlet past Syracuse, and inaugurating Lake Warren, which discharged through the Grand River channel. The Warren beaches lie 20 to 25 feet above the broad, swampy, dune-covered divide at the head of the channel north of Bannister.

DEEPENING.

Chamberlin has accounted for successive steps in the lowering of the level of glacial Lake Chicago by a process of stoping in the bed of the outlet of that lake. The Grand River channel led to Lake Chicago below Grand Rapids, and the river which flowed through this channel had Lake Chicago for its base level of erosion. It would seem certain that a relatively sudden lowering of Lake Chicago would introduce a process of stoping in the Grand River channel. Possibly this accounts for the principal lower terraces in the valley, especially for one that seems rather persistent at a height of 35 to 40 feet above the general channel floor. This terrace seems to represent a relatively stable condition of the outlet river and a long duration of flow with comparatively little deepening. It is to be noted, further, that this terrace appears to be the one that is most closely related to the Arkona beaches. These beaches in the Saginaw basin are very mature, and though they are generally double near the head of the outlet, they differ in altitude by less than 10 feet, generally by not more than 5 to 7 feet. From their mature

character it is evident that the water stood at their level much longer than it did anywhere else. This might be expected from the fact that these beaches represent in time the duration of Lake Maumee after the opening of the outlet near Imlay and the whole life of Lake Arkona and probably that of Lake Whittlesey also. They enter the head of the deeper channel at Maple Rapids at an altitude of 35 to 40 feet above its floor. It seems certain, therefore, that the most prominent terrace is the old floor of the channel during the times of Lakes Arkona and Saginaw—the strongest beach corresponding in time to the strongest terrace. Then sometime later, probably coincident with a drop in the level of Lake Chicago, the river began cutting back from a lower level at its mouth and the old floor was cut away, leaving fragments as terraces along the sides. By the strength of their development and their bowldery, stony surfaces these fragments indicate a relatively old and mature river bed.

A further evidence of the relatively long duration of the outlet with its floor at the terrace level is seen in the relation of the larger tributary streams which enter the channel from the sides. Flat River at Lowell, Grand River at Lyons, and several smaller streams came in more evenly at grade at the terrace level than they do at the present level. Stony and Prairie creeks show this relation as well if not better than the large streams. Further evidence is found in well-defined terraces of the same floor on Grand River above Lyons. It might be thought that these terraces were formed by the deepening of Grand River since the great outlet river abandoned Grand River channel. Grand River is perhaps large enough to give a slender basis of plausibility to this idea, but the present condition of the channel floor shows that Grand River has done virtually no deepening in the channel, except in its own actual bed. Outside of this it has slightly built up the floor by the deposition of silt. Maple River is so very small and feeble that it has accomplished virtually no deepening.

RELATION OF ARKONA BEACHES TO LAKE SAGINAW.

The relation of the present head of the channel to the Arkona beaches is somewhat peculiar and significant. The head is not in the deeply trenched part of the valley but is in a swamp on a wide, flat clay plain sloping gently toward Saginaw Bay, 16 or 17 miles east of Maple Rapids. The divide, which is in a depression so slight that it is scarcely perceptible, is about 58 feet below the level of the upper Arkona beach 2 miles northeast of Elsie.

These relations show clearly that both the original divide and the divide that held so long and changed so little during Lake Arkona were at a considerably higher level. But the divide at the time could not have been higher on the plain where it is now. To be higher it must have been a number of miles farther west—at least as far west as the moraines that cross the river 1 to 3 miles east of Maple Rapids.

At Ithaca the old lake plain slopes gently eastward from the inner base of the moraine, and there is much reason to believe that it did so originally from the east front of the Flint moraine east of Maple Rapids. As the head of the channel receded eastward it was therefore gradually lowered as its place moved down the eastward sloping plain. But with the floor of the channel heavily protected by bowlders, the lowering was slow and required a long time. Only in some such way is it possible to explain the present height of the upper Arkona beach above the divide.

CHAPTER XVI.

GLACIAL LAKE ARKONA.

By Frank B. Taylor.

EARLY INVESTIGATIONS.

The name "Lake Arkona" has recently been applied to that stage of the lake waters in the Huron-Erie-Ontario basin which immediately followed the last stage of Lake Maumee and preceded Lake Whittlesey. Arkona is a village in the Province of Ontario about 50 miles east of Sarnia, where Spencer[1] first observed and named the beaches. The name of the beach was applied to the lake by the writer[2] in 1905. It is in some respects an unfortunate selection, for the beaches are not strong nor typically developed nor even all present at Arkona, only two of them being found there and three being strongly developed in the Black River valley in Michigan, between Applegate and Avoca. No other name, however, has been suggested, and though this designation was first applied with the distinct idea that it would be used only temporarily, it has already appeared in print several times and will be used here pending a better selection.

The first observers of old shore lines in the lake region naturally gave more attention to the stronger lines and so far as known did not mention the Arkona beaches. This is not surprising, for these beaches are extremely faint in nearly all the region in which they occur and are strong only in certain small areas. Spencer,[1] who seems to have been the first to record their existence, observed them in Ontario and then crossed over into Michigan and identified them on the slope west of Port Huron. He shows them in a profile of the beaches in the St. Clair Valley.

In the earlier studies of Gilbert and Leverett on the abandoned beaches in Ohio, Pennsylvania, and western New York, a group of beaches within a vertical interval of 25 or 30 feet was considered to be closely related, probably marking a gradual decline of one lake stage. Gilbert[3] called this series the "Crittenden" beaches, and Mr. Leverett[4] used the same name. Later, in Ontario and Michigan, Spencer's names[5] "Arkona" and "Forest" were applied to the upper and lower beaches of this group, respectively. In his studies of the surface geology of Monroe and Wayne counties in Michigan, Sherzer[6] mapped two Arkona beaches in considerable detail, but reported the presence of only two. Mr. Leverett and the writer found three Arkona ridges in the Ann Arbor quadrangle.[7]

ARKONA BEACHES IN MICHIGAN.

AREAL DISTRIBUTION.[8]

Lake Arkona represents a time (see fig. 6, p. 370) when the ice had withdrawn some distance north of the "thumb." After the beaches were made the ice readvanced, raising the level of the lake waters east of the "thumb" without affecting those west of it, overriding and burying part of the beach on the "thumb" and causing the remainder in the Huron-Erie basin to be

[1] Spencer, J. W., High-level shores in the region of the Great Lakes and their deformation: Am. Jour. Sci., 3d ser., vol. 12, 1891, p. 204.
[2] Taylor, F. B., Relation of Lake Whittlesey to the Arkona beaches: Seventh Ann. Rept. Michigan Acad. Sci., 1905, pp. 30–36.
[3] Geology of Ohio, vol. 1, 1873, p. 554.
[4] Am. Jour. Sci., 3d ser., vol. 50, 1895, pp. 10–20.
[5] Op. cit., p. 203.
[6] Monroe County: Ann. Rept. Michigan State Geol. Survey, 1900, pp. 136–140.
[7] Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1908, p. 7.
[8] As the ice barriers of Lake Arkona are not accurately known no map of this lake is given, but its barriers are supposed to have stood in approximately the same position as those of Lake Warren. (See Pl. XVII, p. 392.)

submerged. This readvance divided the Arkona beaches in Michigan into four distinct areas each of which has a different history: (1) The area in the Saginaw basin in which the Arkona beaches were neither submerged nor modified; (2) the area on the "thumb" in which the beaches were overridden by the ice and destroyed; (3) an area in the Black River valley in which the beaches were submerged but on account of their protected position were not modified; and (4) the main area of Lake Whittlesey, within which the beaches were submerged and greatly modified by storm waves.

UNMODIFIED BEACHES IN SAGINAW BASIN.

When the waters fell from the last stage of Lake Maumee and began the formation of the Arkona beaches, the level at which they worked was determined by the level of the outlet then established. This outlet was westward down the valleys of Maple and Grand rivers to glacial Lake Chicago a few miles west of Grand Rapids. The head of this outlet is near Maple Rapids in northwestern Clinton County. Here two unusually strong gravelly beach ridges, each double in form, enter the valley from the east and northeast and become parallel, as shown in figure 1. (See p. 258.) Their altitude is about 710 feet above sea level, and the channel between them is about three-fourths of a mile wide at its head. The members of each pair are generally close together, are strongly developed, and are composed of sandy gravel. Each ridge is commonly 75 to 200 yards wide and rises 20 to 25 feet above the flats of the former lake bottom. The upper ridge is generally 5 to 10 feet above the lower one, the interval varying slightly.

Northeast of Maple Rapids the northerly pair of beaches have a wide sweep of flat ground in front of them and they grow less strong. East of Ithaca they are about a mile apart. At North Star they are also faint and the descent in front of them is slight. About 5 miles southwest of North Star a gravelly knoll, possibly a kame originally, stands out as an island, the only one on the old shore in this basin. Where they turn westward up the valley of Pine River toward Ithaca the beaches are both perceptibly weaker. Northwest from Ithaca to St. Louis the upper beach is fairly strong and pursues a nearly direct course, but the lower one is generally faint. From Mount Forest the beaches run a little east of north through the extreme northwest corner of Midland County northeastward into northern Gladwin County. In this interval they grow perceptibly weaker and more broken and the lower member is difficult to trace, finally being lost altogether on the sandy plain. The upper ridge is readily distinguished for about 7 miles northeast of Gladwin, beyond which it leaves the border of the morainic ground and is not certainly traceable in the sandy plain. Its altitude 7 miles northeast of Gladwin is 815 feet above sea level (aneroid).

East of Maple Rapids the southerly pair of beaches, as shown in figure 1, diverge slightly, the upper one turning south past the schoolhouse. This beach is very strong to this point but grows rapidly weaker down the valley. The lower beach is not so well defined and keeps a more direct course to the southwest. For 3 or 4 miles east of Maple Rapids the beaches lie upon the face of a bluff and are broken in many places, the lower one especially being difficult to trace. At Eureka the beaches turn south for a mile and then east and are better developed. To the vicinity of Elsie the beaches are both well formed as gravel ridges and are one-fourth to one-half mile apart. From Elsie they run eastward past Chapin to Shiawassee River in fine form. At Chapin, where they are very strongly developed and stand close together with 5 or 6 feet difference in height, they are composed of rather coarser gravel and contain less sand than in most other localities. Eastward from a point north of Elsie the mature character of the foreslope or surf-wasted zone is striking, the ground dropping 20 to 25 feet in 300 to 400 feet, from the front of the lower ridge apparently to a floor that has been wasted by surf pounding for an unusual length of time. This phase of shore lines is in few places so strongly developed as here, though it is almost as strong at many points northeast of Clio.

From Oakley on Shiawassee River the beaches run eastward past Lathrop Corners in strong development, but after turning southeast up the Flint River valley toward Flushing they are much reduced in strength. The lower beach extends nearly north from Flushing on the east side of the river in fairly good development for about 2 miles, where it turns to the northeast.

From here the beaches run in an almost direct line northeastward past Clio, Arbela, Millington, and Juniata, nearly to Cass City. Northeast of Flushing the third beach ridge of this series begins to appear below the others and from Clio northeastward three beaches become more and more distinct. Northeast of Juniata three ridges pass out upon a plain of increasing flatness and are deployed at wider intervals which increases their distinctness as individuals. In this part of their course they are generally composed of gravel, but are in many places covered over with fine sand which has blown in across the region from the west. Two or three miles from Cass City the beaches are buried, partly in sand but mainly in a gravelly plain, probably in large part a delta deposit made at the time of Lake Whittlesey.

From the reentrant angle north of Ubly the main moraine of the Port Huron morainic system, made up of three or four rather irregular subsidiary ridges, runs southwest to Vassar, its complexity gradually disappearing as its western or later parts became water-laid. At Vassar it turns gradually west, passes along the north side of Cass River through Saginaw and on northwestward to a point east of Midland, where it turns gradually north and in northwestern Bay County curves gradually back to the northeast. It was on this moraine that the ice front rested during the time of Lake Whittlesey, when the lake waters east of the "thumb" were raised to the Whittlesey beach and the Arkona beaches were drowned. The Arkona beaches in the Saginaw basin were largely made before the building of this moraine, and it is a notable fact that where they run northeast from Millington toward Cass City the ridges appear to keep their full strength until they are lost in the sand, in spite of the fact that in the last 25 miles they extend up the east side of a rather narrow valley with the main moraine of the Port Huron system forming a great barrier facing them on the west. It is evident on the least reflection that the strong beaches near Cass City could not have been made by wave action at the head of so long and narrow a valley, and hence could not have been made after the main moraine of the Port Huron system was built. The evidence indicates very clearly that the beaches there were made by heavy seas coming from the northwest and passing with full force over the place where the Port Huron system now stands as a range of hills 20 to 60 feet higher than the beaches. Further, although the western slope of the Port Huron system at the level of this beach would have been exposed, if present, to a wide expanse of water, it shows no sign of a beach nor any effects of wave action. It seems entirely clear, therefore, that the Arkona beaches in the Saginaw basin were made before the building of the main moraine of the Port Huron system. The relations seem conclusive in the region southwest of Cass City, and the same phenomena are repeated in three other localities.

On the northwest side of Saginaw Bay, where the Arkona beaches would naturally be expected to come into similar relations with the Port Huron system, the ground is so flat and is so extensively covered with sandy outwash and delta deposits that the beaches, which were probably weak on account of the flatness of the region, are buried and lost long before they reach the front of the Port Huron system. On this account no similarly significant relation of the beaches to the moraine was observed on the west side of the Saginaw basin.

OVERRIDDEN BEACHES ON THE "THUMB."

From a point 2 or 3 miles south of Cass City around the "thumb" to the vicinity of Applegate and Croswell the Arkona beaches were entirely overridden and destroyed by the advance of the ice at the time of the building of the Port Huron system. In all probability the beaches were formed in full strength continuously around the "thumb," passing some distance north of Ubly, but all that part is completely buried under the massive deposit of the morainic system. That this was the case seems clearly established by the fact that south of Applegate and Croswell the Arkona beaches reappear three in number and in full strength and at the same level as in the district southwest of Cass City, when measured along the line of the isobases. The inference as to their strength in the overridden interval is not based on the strength of these beaches in the Saginaw basin, where they stand for the duration of Lake Saginaw in addition to that of Lake Arkona, but on their strength in the Black River valley, where they represent only the duration of Lake Arkona and were under construction for the same length of time as those in the overridden district.

SUBMERGED BEACHES IN BLACK RIVER VALLEY.

The area of the Arkona beaches in the Black River valley is small, but it includes probably the most remarkable evidence of readvance of the continental ice sheet and of resulting effects upon lake waters to be found anywhere in the Great Lakes region or perhaps in the world. It extends for about 20 miles south from Applegate and covers that part of the Arkona beaches which lay in a protected position in the Black River valley while they were submerged by the waters of Lake Whittlesey.

BLACK RIVER BAY.

The Whittlesey (Belmore) beach runs northward from Richmond in fine form and after crossing Mill Creek, about a mile south of Avoca, turns east-northeast and seems to terminate in a great spit at the hamlet of Spring Hill, about 2 miles northeast of Avoca. This spit is a large blunt point standing about 15 feet above the surrounding plain and overlooking the lower ground to the south, east, and north. It has only a narrow westward connection toward Avoca, mainly along the south side of an ill-defined ridge which in some places seems slightly morainic but in general seems scarcely more than an undulating part of the till plain. The head of the spit, which broadens to 50 or 60 rods, is formed of gravel beach ridges built on successively from the southwest and hooking back toward the north and west on the north side. This gives the spit a bold bluff-like front facing east and north, and it was projected far enough eastward from the low ground to give it similar boldness toward the south.

Eastward from the spit at Spring Hill the road passes down a gentle slope for about 2 miles to Black River and then up the western face of the main moraine of the Port Huron system for about a mile, when it again reaches the level of the spit and of the Whittlesey beach. From this road the narrow Black River valley stretches northward for 50 miles to the drainage divide at Ubly, which is slightly below the level of the Whittlesey beach. This valley was occupied in the time of Lake Whittlesey by a long, narrow bay which, except in a narrow strip on the east side extending for about 20 miles north from the entrance, was less than 25 feet deep. The spit at Spring Hill is a gatepost on the west side of the entrance and the gate was 3 miles wide. (See fig. 5, p. 366.)

THE THREE BEACHES.

On the road from the spit down to the river the three Arkona beaches are crossed at right angles at points where they have just turned northward up Black River valley. The upper two beaches on this road are rather faint, but the lower one is fairly well developed. Southeast from the road east of Spring Hill all three are very faint—are, indeed, scarcely traceable. Northward from this road, however, they change within a mile to strong well-formed beaches comparable to the upper Maumee beach in its best development and almost to the Whittlesey and Warren beaches. They stand in most places 10 or 15 feet above their foreslopes and 4 to 10 feet or even more above the plain back of them. They are gravelly beach ridges, which carry a considerable proportion of sand in some places but are of clean gravel in others, and they are fairly strong and continuous. The remarkable character and situation of these three beaches as they pass north from this road seem to justify more detailed description.

FIRST ARKONA BEACH.

On the road east from Spring Hill the first Arkona beach lies three-fourths of a mile east of the great Whittlesey spit and 30 to 35 feet lower. It runs a little east of north through the E. ½ sec. 36 and across the southeast corner of sec. 25, Greenwood Township, and passes into sec. 30, Grant Township. In the first mile it is weak, but it becomes strong and distinct 1¼ miles east of Fargo. (See Pl. XIII, *B*, p. 291.) From here it runs straight north in the western edge of secs. 19 and 18, Grant Township. Here it bends west into eastern secs. 12 and 1, Greenwood Township, and then northeast through sec. 6, Grant Township, into sec. 31, Worth Township. Near the St. Clair-Sanilac county line a faint beach appears 8 or 10 feet above the first Arkona. Its relations to the other beaches are not clear. It is described as beach A on page 369.

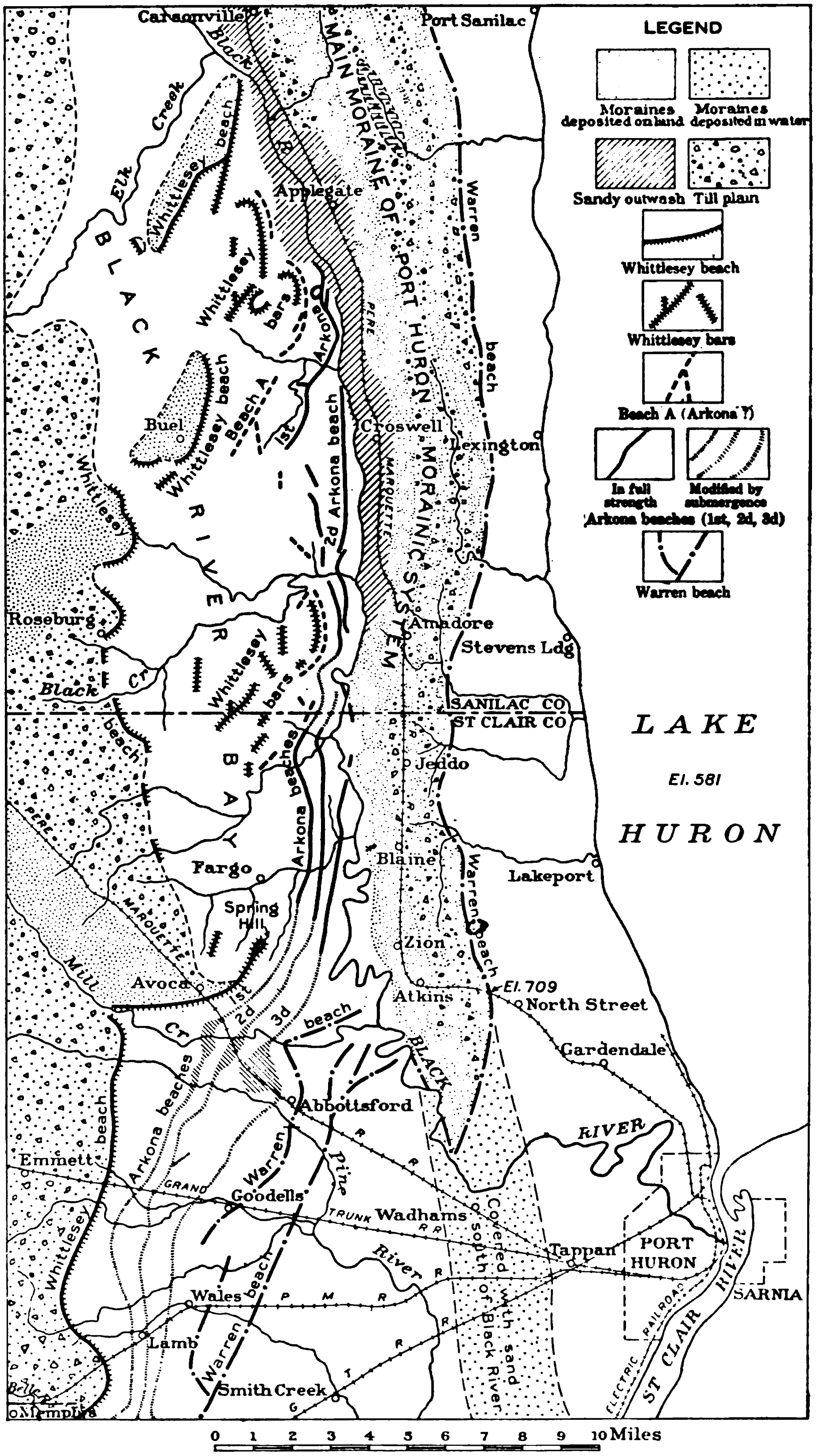


FIGURE 5.—Map showing relations of Whittlesey, Arkona, and Warren beaches to one another and to the Port Huron morainic system.

From the southwest corner of Worth Township the first beach runs northeast through the southeastern part of sec. 30, and thence north through the east side of sec. 19. It is not strong in this interval but is a well-formed gravelly ridge. Farther north it is somewhat broken for about 3 miles. West of Croswell it appears in stronger form, with a faint, weaker ridge (a back line of the middle ridge) along its east base in secs. 31 and 30. In the west part of sec. 19 it turns northeast and runs to the bank of the river in northeast sec. 18, in this section forming a strong barrier between a swamp on the west and the river on the east. Thence, in sec. 7, it turns a little west of north and after forming a sharp spit toward the north near the river, loops around an island west of the spit and then turns northwest along the river for half a mile to the middle of sec. 6, a mile directly south of Applegate and 17½ miles directly north from the Spring Hill road, where it is lost or buried under sandy outwash.

At several points north of the county line which divides Grant and Worth townships this lower member has gaps of a quarter to half a mile and is rather weak in some parts, notably those in secs. 7 and 6, Worth Township, and 31 and 30, Lexington Township. These weak parts, however, seem to be accounted for by the fact that they were formed behind a wider sweep of flat ground with less depth of water. North of a point west of Croswell this member appears to have full strength up to the end.

SECOND ARKONA BEACH.

About half a mile east of the first Arkona beach on the Spring Hill road is another beach ridge which, although faint and low on this road, grows strong within a mile to the north and continues northward close west of the quarter line of the western tier of sections in Grant Township, to sec. 6. Here it bends a little west and then northeast, running over into sec. 31, Worth Township. It is apparently cut away by the river for 1½ miles, but it begins again at the southwest corner of sec. 20, Worth Township, and runs thence almost directly north in fine form and strength past Croswell to the bank of the river at the center of the east side of sec. 19, Lexington Township. At this bend the river appears to have cut the beach away, and apparently there is no hope of finding it on the east side, all possible lines of continuation being covered by sandy outwash from the moraine. A low, rather irregular, and fragmentary ridge of very fine sand that starts near the east side of the river and runs through Croswell and secs. 20 and 17 is evidently a mere modification of the outwash, for it has the same composition and in no way resembles the gravelly beach ridge.

From the Spring Hill road the second Arkona beach ridge runs north 14 miles to the place of its termination. Throughout this whole distance, with the exception of two or three very short intervals, it is strong and clearly developed. At Croswell it passes through the western edge of the village and is a fine, strong ridge with a considerable stretch of low, almost swampy ground west of it. For a mile south of Croswell it shows a tendency to double; the main strong strand lies to the east and the fainter more broken ridge lies close behind it on the west. At its north end it rises barely above the surrounding ground and on its east side appears to be nearly buried in silty deposits.

THIRD ARKONA BEACH.

The third or lowest beach runs northward from the Spring Hill road in a fairly direct line through the center of sec. 31, Grant Township, and then eastward a little, passing out near the northeast corner of sec. 30, and in the next mile turning back to north on the line between secs. 19 and 20 and ending abruptly one-fourth mile farther north, on the line between secs. 7 and 8, at the high bank of Black River. The river is here depressed about 80 feet below the level of the beach, and just beyond the end of the ridge and northwest from it the bank is a freshly cut and vertical bluff of clay with intercalated bedded sand. One-fourth mile to the northeast, on top of the bluff across the river, a short but strong and well-formed gravel beach ridge appears with the altitude and in the line of continuation of the main ridge on the west side of the river. It stands close to the edge of the bluff and extends only 15 or 20 rods north

into the edge of a wood lot, where it is cut away, apparently by a former meander of the river which swung to the east and cut heavily into the high ground.

The situation of the third beach in sec. 8, Grant Township, is truly remarkable. On the road east from Spring Hill the third beach is a trifle more than half a mile west of the river, and it runs at a short distance from the bluff all the way up to sec. 8. In this same interval the rather steep and bold front of the main moraine of the Port Huron system lies close along the east side of the river and in some places is cut by the meandering of the stream. Through secs. 29, 20, 17, and the south half of sec. 8 the foot of the moraine is close to the river. At the little fragment of beach on the east side in sec. 8 the foot of the moraine comes actually in contact with the eastern edge of the beach ridge and a distinct but narrow trough or depression intervenes between the beach and the foot of the moraine. This depression is scarcely more than 50 feet wide; indeed, its slopes consist of the two formations mentioned. Its west side is the eastward face of the gravel ridge, and its east side is the westward face of the moraine. This attitude of face to face contact between the strongly formed beach and the great moraine has not been observed elsewhere, so far as known. From the little trough eastward up the front slope of the great moraine—and this moraine is truly a great one—the surface of the ground rises about 60 feet above the beach ridge within a distance of three-fourths of a mile. The moraine is massive and rugged, and though its basal parts were laid down in shallow water, its upper parts were land-laid and have the distinct hummocky, irregular surface characteristic of such deposits. From its base at the beach ridge over its top and eastward down to the Warren beach along its eastern side is over 2 miles. The moraine fills this whole interval, and it can scarcely be doubted that its thinning backward slope extends a mile or two farther toward Lake Huron, or even to the lake shore.

The fragment of the beach ridge in sec. 8 may have extended northward for some distance and have been cut away by the meanderings of the river, but it is also possible that it was buried under the moraine. In the north edge of sec. 8 and in sec. 5 the river has cut two distinct bights into the face of the moraine, and in these the beach ridge is missing. But in the extreme northwest part of sec. 5 the gravelly beach ridge reappears once more on the east side of the river and runs for one-fourth mile along the edge of the bluff. It is well formed here, but is more nearly overridden by the moraine. Toward the north it is being cut away by the river at its back and is partly buried by the moraine in front. It is again cut away on the bluff in the southwest corner of sec. 32, in Worth Township

One more small fragment of it reappears a quarter of a mile farther north, this time on the west side of the river. Here its identity is perhaps more doubtful; but although it has probably been modified to some extent by the river, it preserves quite distinctly the character of a gravelly beach ridge with a slight depression behind it. This fragment is a quarter of a mile long and is cut away at the edge of the bluff north and south. Farther north no evidence of this beach ridge is found. Through Lexington and Worth townships an apron of fine sandy outwash, one-half to three-fourths of a mile wide, slopes westward from the front of the moraine to the river, and it seems quite probable that this outwash conceals the third Arkona beach. It is a very surprising thing that the beach fragments which stand close against the front of the moraine bear no outwash upon them, although the front of the ice was standing in 45 feet of water. This is discussed in connection with Lake Whittlesey (p. 380). In the north half of Worth Township and the south half of Lexington Township the front of the moraine turns back a little to the east, and it may be that the third Arkona ridge is not buried under the moraine until it reaches a point a mile or more north of Croswell, but is simply hidden under the sandy outwash. From the south edge of Croswell an irregular sandy ridge runs south about 2½ miles. Except for about half a mile, this ridge lies on the east bank of the river and from its position might be taken to be part of the third Arkona beach, but it is not a beach formation. It is apparently composed wholly of fine sand and is very irregular, full of knobs and irregular hollows, and is, in fact, a line of dunes. Thus the lower beach has been identified for 7 miles north of the Spring Hill road.

BEACH A, ARKONA (?).

In the Black River valley there is a beach 10 to 12 feet above the first Arkona beach. It is faint and fragmentary and has the washed-down appearance seen in the other Arkona beaches where they have been modified by submergence south of Spring Hill. One or two small fragments occur in the north edge of St. Clair County, but all of the better parts are in Sanilac County. The best examples lie on the slopes close below the strong Whittlesey bars west of Amadore, west of Croswell, and southwest and west of Applegate.

A few small fragments of beach A lie farther south, but as a continuous ridge it begins rather abruptly near the southwest corner of sec. 30, Worth Township, whence it runs northeast, curving to north through the middle of sec. 19. For 6 miles the ridge is very broken, and the beach seems absent in four gaps 1 to 2 miles wide. A small fragment occurs at the southwest corner of sec. 7 and another 2 miles to the north and a little west. A mile farther northwest a low beach ridge runs north-northeast for 2 miles through secs. 35, 26, and 24, Buel Township. Then after another gap of a mile this beach reappears in stronger form and runs northward along the west line of Lexington Township in secs. 18, 7, and 6. One more fragment runs north about a mile in secs. 35 and 26, Washington Township, to about 1½ miles west of Applegate. A small gravelly patch farther north on the south line of sec. 22 may represent it, but beyond this, if present, it is buried under sandy outwash. This is 20 miles north from the Spring Hill road.

It is possible that beach A is a mere local splitting from the first Arkona beach, due to uplifting and tilting of the land, which affected only the region of this valley, but at present no proof of this is available.

Another possible explanation makes beach A a relative of the Whittlesey beach rather than of the Arkona beaches, for if, as seems to be indicated by its character, the Whittlesey beach was gradually pushed up the slope while it was being made, beach A may be the remains of the Whittlesey beach at its first level. A faint ridge along the base of the Whittlesey beach east of Ypsilanti suggests the same relation. The further fact that it was not found in the Saginaw Valley is significant. On account of these uncertainties, it has not seemed best to designate beach A as the first beach of Lake Arkona, although that may be its real relation.

RELATION OF THE ARKONA BEACHES OF THE BLACK RIVER BAY DISTRICT TO THE PORT HURON MORAINIC SYSTEM AND TO LAKE WHITTLESEY.

The relation of the lower ridge to the two above it in sec. 30, Grant Township, shows how absolutely unique is the relation of the fragment of the third beach east of the river in sec. 8 to the moraine. (See fig. 6.) In sec. 30 the three beach ridges lie upon a gentle slope which declines eastward toward Black River and the beach ridges are like steps going down the slope. The ridges face eastward over lower ground and within a few rods back of each ridge the clayey plain rises gradually to a higher level. Thus it is totally out of the question to think of these ridges or any one of them as made by waves coming from the west. The waves came distinctly from the east and could not have come from any other direction. Yet as one follows the lower ridge up to sec. 8 and sees the front of the great moraine coming nearer and nearer, until at the little fragment on the east side of the river the foot of the moraine actually touches the eastward face of the beach ridge, and as one sees the massive bulk and height to which the moraine is piled directly in front, the situation and history of this locality become little short of dramatic. Standing on the beach and endeavoring to restore in imagination the conditions which existed when that beach was made, one must imagine the entire bulk of the great moraine to be removed and in its place a wide sweep of waters deepening in front of or eastward from the beach over the area where the moraine now stands.

The facts and relations here are so clear and plain that this description, drawn in the effort to reconstruct the conditions and events of the past, is not fanciful but portrays things as they really occurred. When the beach ridge was being made, the massive moraine was not there, nor was the great ice sheet which built the moraine. At that time the ice front must have

stood many miles away to the east or northeast. It was evidently far enough away to allow the heavy seas of Lake Arkona to sweep in from the east to the beach. Here is an ideal opportunity to measure or at least to make a very close estimate of the amount of drift deposited and the work of the ice sheet in the building of a great moraine.

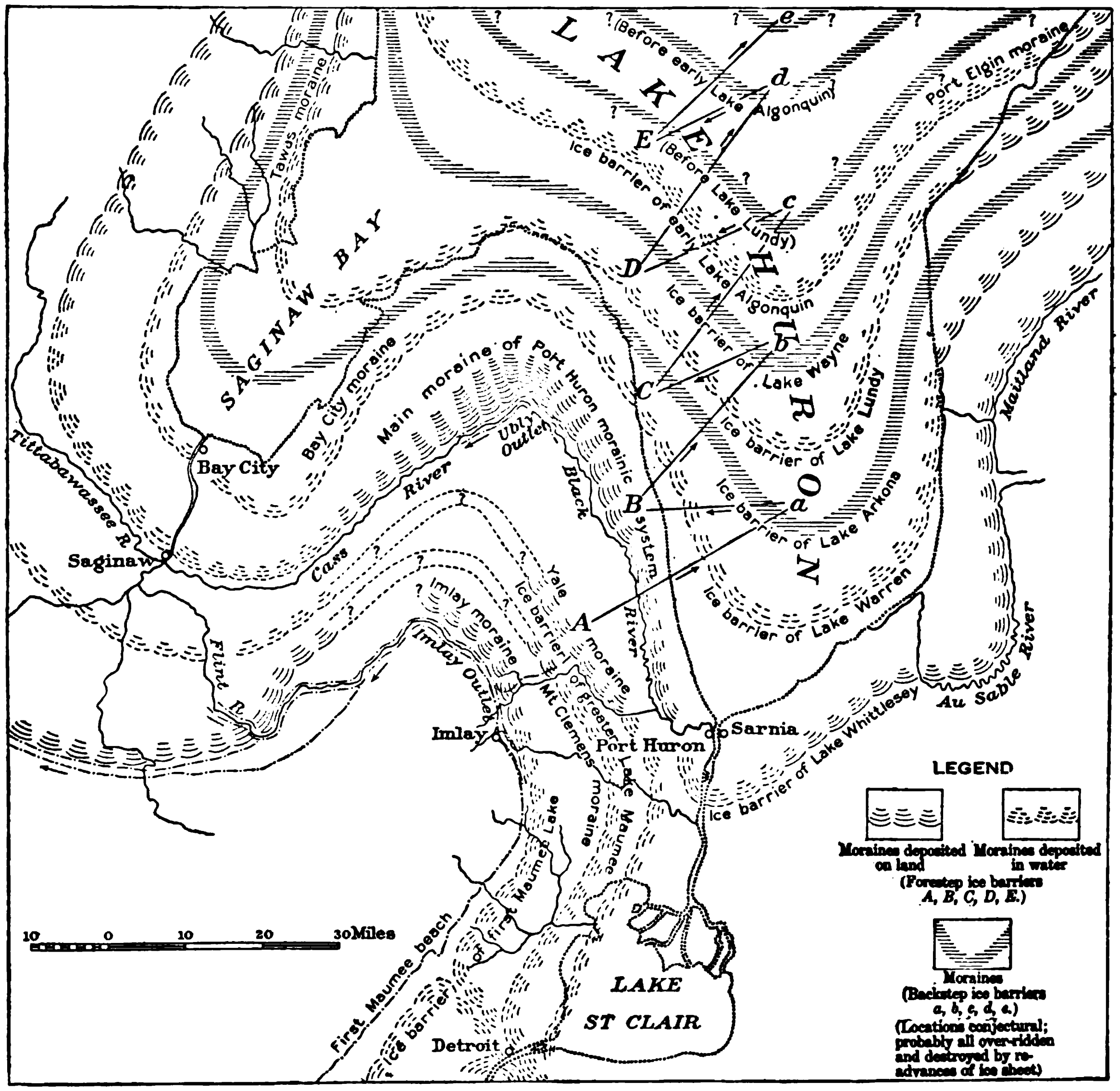


FIGURE 6.—Diagram showing lake stages as affected by glacial oscillations on the "thumb" of Michigan.

SUBMERGED AND MODIFIED ARKONA BEACHES BETWEEN SPRING HILL AND THE OHIO LINE.

From the gateway between Spring Hill and Zion to the State line of Ohio in southeastern Lenawee County the three Arkona beaches are faint and hard to trace, and, indeed, the same character continues throughout Ohio and Pennsylvania and western New York. Detailed descriptions, however, will be confined to the part in Michigan.

MODIFICATION OF THE BEACHES.

Between Spring Hill and the Ohio State line the Arkona beaches do not show the characters normal to those in the Saginaw and Black River valleys. The slope southeast of Spring Hill at the Arkona levels bears scarcely anything which could be called a beach ridge; it carries only

ill-defined belts of gravel or gravelly soil which mark the former position of such ridges. In general the first belt is the faintest, the second is slightly stronger, and the third is the strongest of the three, being in some places easily recognized as a distinct ridge. This is what would be expected if their modification was due to the passage of storm waves over them. for naturally the most deeply submerged ridge would be the least modified.

In order to trace these ridges and make sure of their continuity as separate individuals it was necessary to go over part of the ground where they occur very thoroughly. The beaches were studied with particular care as to details in the interval between Spring Hill and Richmond and again at several places farther southwest. In some places no definite beach ridge nor other feature that suggested wave action was seen for 4 or 5 miles, but generally a careful examination of the shallow sections exposed along the stream banks or roadsides revealed the gravel belts which mark the former position of the beach ridges. In a very few places even this slight evidence failed, and nothing at all representing the beach was seen. However, where all else was lacking, a faintly ridged strip of ground 10 to 30 rods wide, distinctly more gravelly than the flatter intervening areas and decidedly more gravelly than is characteristic of the till of the region, was nearly always found. The beaches were studied with particular care in Kenokee, Wales, Columbus, and Richmond townships. In Wales and Kenokee townships excursions on foot and an examination of the soil showed distinctly three gravelly belts, in places a foot or two higher than the adjacent ground, but scarcely perceptible to the eye as ridges. In driving, however, these belts might easily be passed unnoticed, even by those who have had extensive experience in the study of shore-line features. This shows to what an extent their physical expression has been destroyed.

The finding of such indefinite features in one locality, or in several widely separated localities, could hardly be accepted as proof of the former existence of the beaches along these lines. But when the study on foot was carried over a wide area it was found that the gravel belts are not only distinct from each other, but that they run continuously across the country with uniform relations to the other beaches and with uniform vertical intervals between them. In these townships measurements of their altitudes show that they rise toward the northeast at the same rate as the Whittlesey beach (about 1 foot a mile). Between these belts the soil is distinctly less gravelly.

These gravel belts were followed almost continuously from the vicinity of Lenox and Richmond northward into the Black River valley before it was known that there were any Arkona beaches in that valley. Their development into three robust, unmodified beach ridges north of Spring Hill was not foreseen and can hardly be regarded in any other light than as a remarkable confirmation of the growing belief that the three gravel belts were in reality the remains of gravelly beach ridges which had been washed away and almost entirely obliterated by the oversweeping seas of Lake Whittlesey.

TEXTURE.

The most peculiar characteristic of the gravel belts—noted in detail in Kenokee and Wales townships but generally characteristic of the modified Arkona beaches—is their stiff clayey quality. Unlike other beaches, which are sandy or gravelly and rather loose in texture, the soil of these gravel belts is very stiff and forms clods that endure for a long time. Only their continuation for miles across the country, their persistent levels, and their final mergence into the strong ridges of the Black River valley make it certain that even though they are so impregnated with clay and form so firm a surface underfoot they are nevertheless the remaining basal parts of beach ridges.

The composition of these gravelly belts, however, is not that of the original Arkona beaches. It results from the infiltration of fine clay into the remains of the beaches after their upper parts had been washed away by oversweeping storm waves of Lake Whittlesey. If the depth of water over the Arkona ridges during the time of Lake Whittlesey be considered, it seems certain that the washing away of the gravelly ridges was accomplished mainly by oscillating movements of the water on the lake bottom. The oscillating water was evidently able to move pebbles of con-

siderable size in the district of these modified beaches and the remarkable way in which the gravel taken from them was swept up the slope and built into the Whittlesey beach is a fine illustration of the general principle that surf, beating upon an offshore shallow bottom, tends to loosen coarse material and carry it up the slope. Sometimes currents along the shore domineer over the tendency to on-shore deposition and the coarse material in such cases is carried along to some more favorable place of deposit. The Arkona ridges were swept away down to their roots or basal parts which by that time presented so little relief upon the lake bottom as to give the oscillating waters no effective hold at any particular point. It was mainly after this condition had been attained and during times of quiet that the clay was deposited in the gravel.

It was probably in some such way as this that the Arkona beaches were transformed from the robust type seen in the Black River valley to the present low, clayey, gravelly belts.

DISTRIBUTION.

As far south as Lenox the three Arkona gravel belts are distinct. Beyond, there are a few intervals in which only two are discernible. Still farther southwest the first and second ridges draw closer together and the vertical interval between them diminishes until it is often difficult to distinguish the two. The three ridges are distinguishable some distance beyond Britton, where the upper two are of very nearly the same height.

The same occurrence of three beaches was noted in the Saginaw basin between Flushing and Cass City, but west of Flushing only two beaches appear. Those observed in the Saginaw basin resemble very closely in their relations, though not in their strength nor in their modifications, those running southwest from Spring Hill. In the Saginaw basin the Arkona beaches were not submerged, but they were uplifted. Nothing, however, like beach A in the Black River valley was observed. The full strength of the Arkona beach ridges in the northern parts of the two valleys—near Cass City and near Croswell—seems to make it clear that the ice barrier at the time of Lake Arkona stood at least 25 miles back—far enough away to allow of a heavy surf on shore, apparently as heavy at Cass City and Croswell as at other places farther south.

SUBMERGED DELTAS.

The low gravelly belts which represent the beaches of Lake Arkona are splendidly supplemented by the deltas that were built in this lake. Not only are these deltas strongly developed and prominent as sedimentary deposits, but they are modified in precisely the same way as the beach ridges.

The formations here described as deltas in Lake Arkona were not at first recognized as such, but were explained as subaqueous extensions of deltas of Lake Whittlesey. Their unusual characters, however, were not satisfactorily explained in this way, and their true nature was recognized only when the modified beaches of Lake Arkona had been traced and their peculiarities explained. It then became apparent that the deltas lay at the same general level as the modified Arkona beaches and that their peculiarities were due to submergence.

The gravel belts representing the beaches are generally somewhat expanded wherever they cross stream courses of even moderate size. Instances occur on Mill Creek southeast of Avoca, and a distinct delta deposit appears to be connected with the lower Arkona beach a mile or so northwest of Abbottsford station. The best examples, however, of Arkona deltas were found farther south in connection with some of the larger streams, most notably on Clinton River above Utica, on Rouge River below Plymouth, on Huron River below Ypsilanti, on Saline River at Milan, and on Raisin River near Blissfield. The best of all is the delta of the Huron southeast of Ypsilanti, and this and the delta at Milan were studied in some detail.

The delta of the Huron is a plain 4 or 5 miles wide with an almost semicircular southeast front. This delta, and in fact all of the Arkona deltas, protrude farther into the lake bed than do the deltas of any other stage of the lake waters. This relation of the Huron delta in Lake Arkona is well shown on the map in the Ann Arbor folio.

The Huron delta seems very flat to the eye but slopes gently toward its edge. The exceptional quality of its soil was noticed by Sherzer in his study of the surface features of Wayne County. Upstream it consists of very coarse gravel and some sand, growing noticeably finer toward the edge. Exposures in the central part show 5 or 6 feet of gravel.

The special characteristic of this soil, like that of the gravel belts that mark the washed-away Arkona ridges, is its stiffness or hardness. The gravel and sand do not make a light, friable soil, like that of unmodified deltas, but one that is very stiff on account of the clay which it contains. Clods are common and rather resistant.

Some of the Arkona deltas show another peculiar modification due to submergence and the work of storm waves. The most notable example is on the delta of the Huron 5 miles southeast and east of Ypsilanti. For a width of about 6 miles along the shore the delta was built out into the lake more than 2 miles beyond the general shore line. After submergence, the storm waves of Lake Whittlesey running in toward the shore, struck the front of this delta and tore loose much of it, building the material into a great, broad ridge 15 to 20 feet high and three or four times as broad as the strongest ordinary beach ridge. The inner area of the delta is to the eye a perfectly flat plain and is composed of gravel stiffened by a moderate admixture of clay. But the whole front of the delta is bordered by great broad, smooth, gravel ridges, the strongest one along the outer front with two or three weaker ones behind. These ridges correspond very closely and in fact are continuous with the Arkona ridges, but are overgrown in their proportions. The best example observed runs west through the south part of secs. 31 and 30, Van Buren Township and is repeated less perfectly on the north side of Huron River. The same characters, but not so strongly developed, may be seen at Milan and below Plymouth and Rochester. It seems certain that these are forms produced by modification during submergence and are not normal Arkona deltas nor normal unmodified Arkona beaches. They are much like the heavy beach ridges which fringe the outer border or front of some of the deltas of Lake Whittlesey, notably those at Plymouth and below Ypsilanti, but they are so modified that they can no longer be regarded as normal beach ridges.

ARKONA BEACHES IN OHIO, PENNSYLVANIA, AND NEW YORK.

In the summer of 1905 a month was spent by the writer, under the direction of Prof. T. C. Chamberlin, studying the Arkona beaches in Ohio and farther east. Two Arkona ridges of fairly good development, but with the usual modified characters, were found to extend from the Ohio-Michigan line 5 miles northwest of Sylvania, Ohio, to within 2 or 3 miles of Napoleon on the north side of Maumee River, where they appear to fade out. South of Napoleon a sandy gravelly coating on the till plain appears to be an Arkona delta of Maumee River. From Napoleon eastward the investigation had the character of a rapid reconnaissance rather than of a detailed study, the beaches being looked for only at intervals of 15 or 20 miles. Southeast of Napoleon and eastward to the vicinity of Bradford the horizon at which the Arkona beaches are supposed to occur is on an extremely flat clay plain, and in this interval no certain evidence of the beaches was found, though some might be discovered by more detailed search. Farther east, in the vicinity of Bellevue, the shore of Lake Arkona faced northwest and carried dunes. The dune deposit is irregular and patchy, but it appears to mark the Arkona level, being about 700 feet above sea level and lying as elsewhere between the Whittlesey and Warren beaches. Eastward to Cleveland and thence along the narrow bench at the base of the escarpment into western New York the Arkona beaches [1] are fairly strong locally, though broken and fragmentary in places. In New York State the Arkona beaches seem to gain strength imperceptibly; and after passing the Cattaraugus embayment and turning toward the north and northeast, they become stronger and stronger and show progressively less modification. Near Hamburg, Orchard Park, Spring Brook, and Marilla the Arkona ridges are as strong and robust and as little affected by modification subsequent to their original making as the beaches in the Black River valley in Michigan. They keep on northeastward through Alden for a mile or two and appear to end abruptly beneath gravelly deposits laid down in the valley of Ellicott Creek by

[1] Parts of this beach were traced by Mr. Leverett and are discussed in Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 764 and 766.

ice-border drainage which came from the east along the front of the ice sheet while the ice front rested on the Alden moraine. The moraine stands about half a mile north and northwest of the termination of the Arkona beaches and the general crest of the moraine is at about the same level, with several knobs rising higher. The moraine runs west-southwest to the shore of Lake Erie, 5 or 6 miles south of Buffalo. When the ice rested here during the time of Lake Whittlesey, a long, narrow bay, 5 miles wide at Orchard Park, ran northeast between the ice and the land for 20 miles. The Arkona beaches, submerged under the waters of this bay, were well protected. The upper Arkona ridge at Alden has an altitude of about 865 feet. At Marilla, a few miles to the southwest, its altitude is about 850 feet, and that of the fading Whittlesey beach is a little more than 900 feet. The situation here is the same as in the Black River valley in Michigan, except that the New York area is small and is not so distinctly inclosed and protected.

ARKONA BEACHES IN ONTARIO.

The Arkona beaches were observed and their altitudes measured by Spencer at several places in Ontario. In one area on the east side of the south arm of Lake Huron they have been studied by the writer in almost as much detail as in southeastern Michigan. Two of them occur at the village of Arkona on high ground that projects northwest. The ice, readvancing to build the Port Huron morainic system, came close to this point and obliterated the beaches for a few miles but did not disturb those in the long stretch of the valley of Au Sable River to the east and north. In this valley two Arkona beaches are finely developed from the vicinity of Ailsa Craig northward to a point west of Clinton, where they disappear under outwash.

The conditions here almost precisely duplicate those in the Black River valley north of Spring Hill but were not quite so favorable in providing protection and preservation, because the mouth of the Au Sable at the time of Lake Whittlesey was wider than that at Spring Hill and the heavy seas rolled into the valley with greater variation of direction and probably with greater power. In the Au Sable Valley only one of the Arkona beaches is strikingly strong and well preserved, but this one is truly remarkable. Some faint traces were found of a third beach which probably belongs to the Arkona group. In that part of the Au Sable Valley between Arkona and Ailsa Craig, the Au Sable has meandered right along the line of the best-preserved Arkona beach. Some detached gravel deposits which look like fragments of a beach ridge and occur in suggestive alignment and constancy of level probably represent the continuation of the stronger ridge westward, but the evidence for the beaches west of Ailsa Craig is rather poor. If the beaches of the Black River valley did not exist those of the Au Sable Valley in Ontario would be regarded as truly remarkable. They point to precisely the same conclusions as to the formation of the Arkona beaches before the building of the main moraine of the Port Huron system and the Whittlesey beach, and they show that the ice readvanced to the Port Huron system, burying the Arkona beaches north of a point west of Clinton and causing those south of that point to be submerged but preserved, in precisely the same way as in the Black River valley. Along the east side of this valley the Whittlesey beach occurs in the same relation as in Michigan, but lacks something of the strength and unique character shown there.

South of the village of Arkona, two Arkona beaches are readily traced as far as Watford, where they turn eastward. In this interval they were exposed openly to the sweep of heavy Whittlesey storm waves from the west and southwest and were modified just as were those in Michigan, though they were in few places rendered so faint as between Lenox and Spring Hill.

The Arkona beach is mentioned by Spencer in two or three localities farther east, but no further observations on it have been made as yet by the writer. In still another locality, which has not yet been investigated, these beaches will probably be found in a good state of preservation—submerged and protected but not overridden. This area lies north and northwest of Copetown.

ALTITUDE OF THE BEACHES.

In the Ann Arbor quadrangle the Arkona beaches have altitudes of about 708 to 710 feet for the highest ridge, 700 to 702 for the middle, and 694 to 696 feet for the lowest. This is in the area of horizontality. These altitudes continue for a few miles north of Birmingham, beyond which the beaches rise toward the northeast. Near Croswell the measurements are all by aneroid barometer. At this place beach A has an altitude of about 755 feet, the first beach about 747 feet, and the second beach about 740 feet. The third beach is not represented there, but in Grant Township it is 9 or 10 feet below the second ridge. The first beach rises about 37 feet, the second beach about 30 feet, and the third beach about 20 feet. Thus the vertical interval between the first and third Arkona beaches is 14 to 16 feet in the area of horizontality, but increases to about 27 feet in the vicinity of Applegate. This northward increase of vertical interval seems to show a slight movement of uplift while the Arkona beaches were being made.

In Ohio and eastward, within the area of horizontality, few accurate measures of altitude on the Arkona beaches are at hand. They are so faint that they are not used as roads to any extent, and the topographic maps show no altitudes that are certainly on the crest. The upper one is a little above 705 to 708 feet where measured and the lower one 8 or 10 feet lower. Eastward, from Cleveland, they rise at first gently and then, north of Silver Creek, N. Y., at the rate of about 2 feet to the mile. At Alden the upper beach is about 865 feet above sea level and the lower about 10 feet lower, indicating a rise of about 155 feet from the area of horizontality. In Ontario the altitude southwest of Clinton is about 745 feet (aneroid). It is not yet known certainly which one of the Arkona ridges it is that is so strong in the Au Sable Valley, but it is not the highest. This indicates a rise of 30 to 35 feet. The greater rise in New York appears to be due to the greater distance of that locality from the area of horizontality in the direction of uplift.

From what is now known it appears that the Arkona, Whittlesey, and Warren beaches all rise together at nearly the same rate in both the western and eastern districts. The great uplift came after the making of those beaches; only a slight uplift had occurred before, as recorded in the Maumee beaches.

In some respects, especially in the matter of beaches modified by submergence, Lake Arkona is the most remarkable of the glacial lakes. Lake Maumee had a similar though briefer history during the making of its lowest and middle beaches.

GLACIAL BARRIERS.

Lake Arkona, which was about three times as large as the present Lake Erie, existed during the pause after a recession of the ice front and before a readvance. The lake was held in by two ice dams, one stretching across the south part of the Lake Huron basin and the other across the west end of the Lake Ontario basin. The readvance of the ice which ended Lake Arkona and raised the Huron-Erie waters to the level of the Whittlesey beach affected both of the ice dams, and as a consequence both of the correlative moraines and all the beaches leading up to them were partly overridden and obliterated.

It is therefore to some extent a matter of conjecture as to where the ice barriers to Lake Arkona stood, though both may be located somewhat closely. The very considerable strength of the Arkona ridges at their north terminal points on the two sides of the "thumb" seem to make it necessary to suppose that when these ridges were made the ice front was at least 25 miles away on lines at right angles to the general trend of the shore. The character and relations of the Arkona ridges at Alden, N. Y., and still more of those near Clinton, Ontaiio, bear out this conclusion. The facts seem also to favor a relatively long duration for Lake Arkona, according well in this respect with the idea that the readvance to the Port Huron morainic system was a movement of more than minor importance.

The eastern barrier lay in the basin of Lake Ontario, in the western half conforming rather closely to the outline of the present lake but in the eastern half expanding over the higher ground. Narrow arms of Lake Arkona reached eastward beyond the Genesee Valley and around the north side to a point north or northeast of Toronto. The evidence now available indicates that the barriers of Lake Arkona stood in about the same position as for Lake Warren, the former marking a climax of retreat and the latter a climax of readvance.

On the other hand, retreat for much more than 25 miles would have opened lower outlets at other points. At the next climax of retreat this happened and the lake level fell below the head of the Grand River channel, forming the Wayne beach and draining eastward past Syracuse, N. Y.

Thus, while the place of the ice barriers of Lake Arkona can not be definitely determined by direct evidence, there are rather definite limits beyond which the barriers can not have retreated without opening new outlets and lowering the lake. The approximate position of the western ice barrier of Lake Arkona is shown in figure 6 (p. 370). The positions of the eastern barriers of Lakes Whittlesey and Warren are shown in a diagram on page 18 of the Niagara folio,[1] and the probable positions of the barriers of Lakes Arkona and Wayne in that region are discussed in connection with glacial Lake Wayne. (See p. 391.)

CORRELATIVES OF LAKE ARKONA.

Lake Chicago had attained nearly its maximum size as an independent lake at the time of Lake Arkona, but Lake Duluth had not yet come into existence. In New York most of the Finger Lakes had united with Lake Arkona, but probably the more easterly ones had not.

[1] Niagara folio (No. 190), Geol. Atlas U. S., U. S. Geol. Survey, 1913.

CHAPTER XVII.

GLACIAL LAKE WHITTLESEY.

By Frank B. Taylor.

GENERAL FEATURES.

The history of Lakes Whittlesey and Arkona is so intimately interwoven that a description of either one involves many references to the other. Although Lake Whittlesey came after Lake Arkona in time, it stood at a higher level, coming into existence in consequence of a readvance of the ice front up the slope of the "thumb" to Ubly. This readvance raised the waters of the Huron-Erie basin to the level of the Whittlesey (Belmore) beach.

The Whittlesey beach is one of the strongest and best developed in the Great Lakes region. It was recognized as a "lake ridge" in Ohio and Michigan at an early day and in many places was used by the early inhabitants as a highway. Mr. Leverett[1] has published an account of the early literature relating to this beach and has described the beach itself in detail. It does not seem necessary to do more here than to summarize his description briefly and to add a few recently ascertained particulars.

WHITTLESEY BEACH IN MICHIGAN.

GENERAL DISTRIBUTION.

The Whittlesey beach lies below the Maumee beaches and above the Arkona. From the Ohio-Michigan line directly south of Adrian it runs north nearly to Adrian and thence nearly straight northeast for about 80 miles to Romeo, where it turns east and southeast to Richmond. Here it turns again at a sharp angle and runs directly north to Avoca and then northeast to a large spit at Spring Hill. Northward from this point it takes an irregular course to the head of the outlet at Ubly. North of Spring Hill it is faint where it formed the west shore of the Black River Bay of Lake Whittlesey, but it is strongly developed on many bars and islands that existed in this bay. It fades out in the shallow extension of the bay northward from Carsonville. (See Pl. XVI.)

BETWEEN THE OHIO LINE AND SPRING HILL.

The Whittlesey beach crosses the Ohio line in the southwest corner of sec. 4, Ogden Township, Lenawee County, where it is a strong ridge of sandy gravel convex to the east. About 1¾ miles east of this point or about 1½ miles northwest of Metamora, Ohio, an oval-shaped island fragment of the Whittlesey beach less than an eighth of a mile long and composed wholly of beach gravel rises 6 or 7 feet above the surrounding clay plain. Such a feature is very exceptional on the openly exposed shores of the glacial lakes in a region so flat as this. Where the country is hilly, as in western New York along the line of this beach, islands were common enough, and there were many in Black River Bay north of Spring Hill.

After running about 10 miles a little west of north in rather weaker expression, the beach turns northeast along the inner side of the Defiance moraine, passing about 3 miles east of Adrian, and is crossed by the Wabash Railroad at Holloway. Five miles east of Tecumseh it enters the Ann Arbor quadrangle. Thence it runs northeast through Lake Ridge and York, passes 3 miles east of Ypsilanti, and goes through Cherry Hill to Plymouth. In this area it has been traced in detail by Mr. Leverett.[2] It is generally a very strong ridge, with rather

[1] Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 741–742, 745–757.
[2] Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1908, pp. 7–8.

uncommon heigth above the plain in front of it and generally with considerable height above the land behind it.

East of Ypsilanti the delta deposits made by Huron River in Lake Maumee caused the line of the beach to bulge about a mile eastward beyond its general course. Where the road leading west from Denton crosses it, its front presents the characteristic bold relief. One to two miles north of this point a finely formed spit was built out for about a mile across some low ground west of the main ridge. Along the front of the delta the ridge is uncommonly strong, and the height to which it rises above the delta plain back of it seems to indicate that the beach was pushed up the slope slightly by the rising of the lake while it was being made. It is developed in unusual strength at Plymouth in connection with the delta of Rouge River. At Birmingham it is carried about 3 miles east of its general trend by the low, broad ridge of the Detroit interlobate moraine. It continues thence in a direct line and in fine form and strength, passing a mile east of Rochester, half a mile west of Washington, and 1½ miles southeast of Romeo. A bowldery, morainic tract 3 miles southeast of Romeo rose high enough to catch this beach, and another small fragment occurs a mile farther east. Behind these outlying fragments the main ridge is weaker, but toward Armada and thence southeastward to Richmond it is very strong, standing out boldly not less than 20 to 25 feet above the plain in front of it and in some places 10 or 15 feet above the ground back of it. It is followed by the main highway of the region. In sec. 33, Armada Township, it crosses the trench of a small creek like a high railroad embankment 15 to 20 rods wide. The creek is trenched about 15 feet in the plain, above which the crest of the beach ridge rises fully 25 feet.

At Richmond the Whittlesey beach turns an acute angle and runs directly north to Memphis. From the east bank of Belle River it runs northeast about 2 miles and after curving northwest continues north and northeast in slightly reduced strength to Mill Creek, 1½ miles west of Avoca. From this point it runs east and northeast to Spring Hill, where it seems to end in a bulblike spit made up of several closely set beach ridges that turn their points back to the northwest. This spit stands 12 to 15 feet above the plain all around it excepting toward the west, where a low morainic ridge rises to its level.

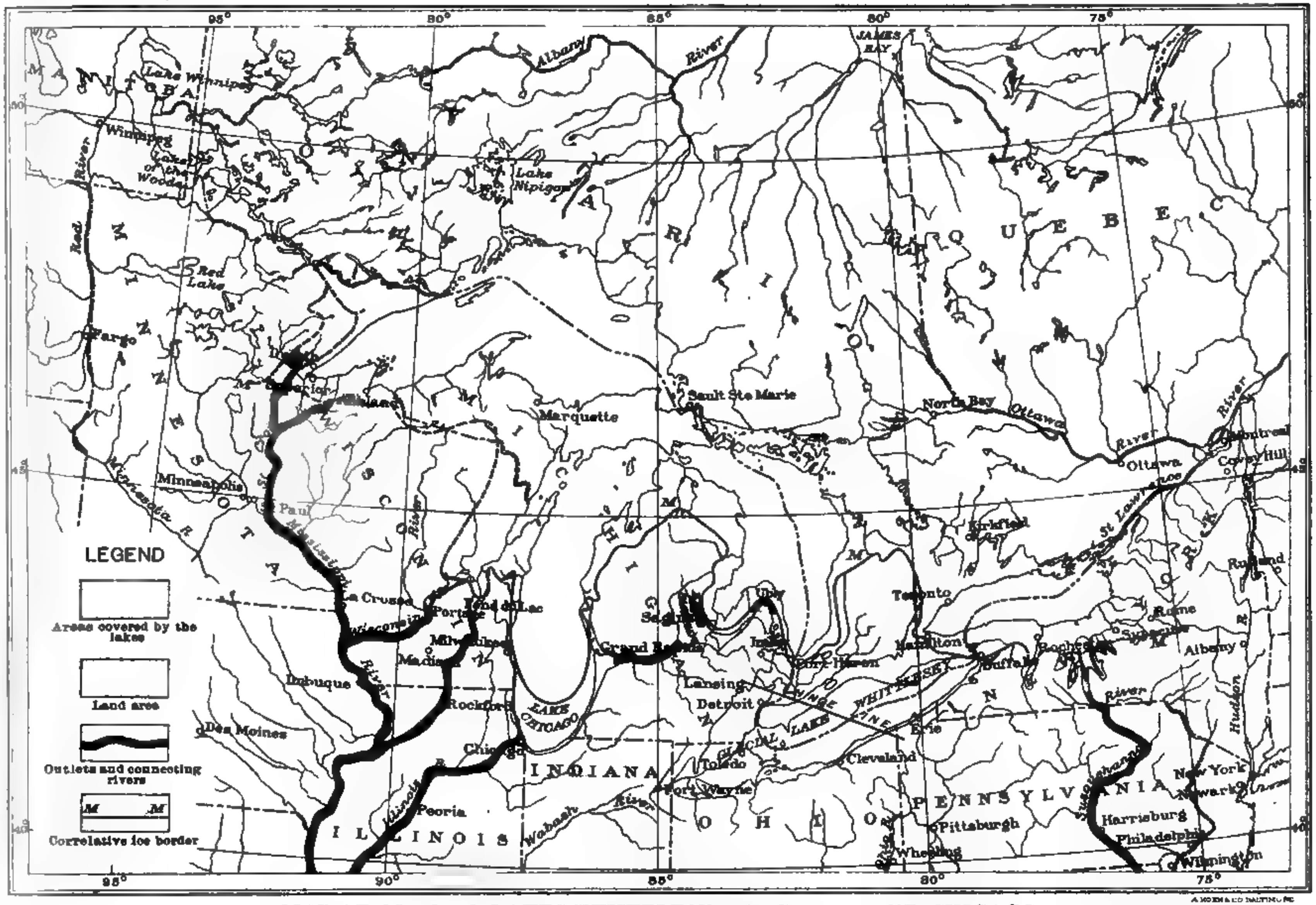
WHITTLESEY BEACH IN BLACK RIVER BAY.

The gateway into Black River Bay of Lake Whittlesey was between Spring Hill and the front of the main moraine of the Port Huron system at Zion, 3 miles to the east. Between Spring Hill and Carsonville there are a considerable number of fragments of the Whittlesey beach. They are all fragments, however, and are extremely irregular in their arrangement. Most of them were simply bars in the shallow bay without any connection with the shore, and all are on the western side of the deeper trough of the bay which runs northward along the east side nearly to Applegate. (See fig. 5, p. 366.) North of Carsonville Black River Bay was so shallow that wave action was ineffective and no distinct beach was found in the few accessible places of that swampy district.

Along the west side of the bay south of Carsonville no distinct shore line was found north of a point opposite Buel, though several bars and beaches on islands are well developed farther north in the western part of the bay. A beach is developed along the west shore both north and south of Roseburg, but it is faint and fragmentary and fades toward the south at the back of the wide flats northwest of Spring Hill.

The east shore of Black River Bay was the front of the main moraine of the Port Huron system or of the ice sheet while it was building that moraine. Between Zion and Applegate the front of this moraine at the Lake Whittlesey level was carefully examined for shore lines but nothing of a wave-made character was found; only a few small kames or gravelly deposits of outwash and in one or two places fine sandy outwash that had been blown up into dunes.

Some further description is needed to show the conditions in Black River Bay at the time of Lake Whittlesey. At that time a relatively narrow trough of deeper water, with its western margin marked by the upper of the three Arkona beaches, extended northward along the axis of



MAP OF GLACIAL LAKES WHITTLESEY, SAGINAW, AND CHICAGO

By Frank B. Taylor and Frank Leverett
Data for eastern Wisconsin by Wm. C. Alden

100 0 100 200 300 Miles

1914

the valley from the gateway at Spring Hill to the vicinity of Croswell and Applegate. Westward from this was a wide flat in which the water was shallow, and west and north of the drift ridges which obstruct the valley at Buel, 3 miles west of Applegate, shallow water of narrower width stretched away to the head of the bay at Ubly. The greatest width was not over 7 or 8 miles, and the average was not over 3 or 4 miles. In times of southerly or southwesterly gales on Lake Whittlesey heavy seas entered the gateway and rolled up the axis of the deeper trough with comparative ease. The Whittlesey bars, which stand close to the western edge of the trough—the one 2½ miles west of Amadore and west and southwest of Applegate—are particularly strong. But the waves could not turn abruptly westward with much force over the wide flats northwest of Spring Hill and were so weakened there that they did little work. All along the trough the waves that ran out over the flats to the west were slackened and deflected into a westward or northwestward course and were relatively feeble where they struck against the land at the west side of the flats. Thus the work done in this valley at the time of Lake Whittlesey appears to have been accomplished almost entirely by waves coming from the southeast or east. As all Whittlesey bars in this valley are in the shallow area west of the trough, it is entirely natural that the effects of wave work should be placed as they are, facing east or southeast. Although the waters reached for many miles north and northwest they were very shallow, and although the gales from that direction are more frequent and prolonged than those from the south they caused no effective wave action.

In view of the remarkable preservation of the Arkona beaches in the Black River valley north of Spring Hill, it is very significant that careful search over the westward slope of the main moraine of the Port Huron system on the east side of Black River has revealed no corresponding beach ridge nor other wave-made features. A few small gravelly or sandy outwash deposits from the ice, made apparently at the level of Lake Whittlesey, are all that appear. Manifestly, the main moraine of the Port Huron system, or rather the ice mass which deposited it, constituted the east side or bank of the trough up which the waves ran into the Black River Bay of Lake Whittlesey. As the moraine was built by ice which advanced to the position of the moraine and did its work after the formation of the Arkona beaches, it could not bear any record of those beaches on its front. But during the time of Lake Whittlesey the moraine and the ice which was building it were standing there, and the moraine might be expected to bear at least a few faint evidences of wave action. Evidently, however, either the ice itself formed the shore, or readvance of the ice or outwash or the erosion of streams issuing from the ice obliterated the marks that the waves produced on the face of the new moraine. The remarkable immunity of the whole face of this moraine from all the wave action that affected the shores on the west side of Black River is evidence enough that the building of the moraine marks an epoch in the history of the lake waters. The ice lobe pushed rapidly southward, overriding and destroying the beaches that lay in its path and setting definite limits to those that it left and to those that were made while it held its place.

It would hardly seem possible for those who doubt the reality of the land ice sheet and its great function as a dam or barrier, retaining lakes as large as those here described, to resist the power of such facts as these. Evidently, before the ice could move up the slope out of the basin of Lake Huron to the position of this moraine it must have been solid; and if it came from the north or northeast it must have filled the entire basin of the lake. In order to flow toward its edge and drive its basal parts up the slope it must have been higher over the central part of the basin than around its edges, and such an ice mass capable of transporting and depositing such a body of drift as the Port Huron system was surely competent to be the retaining barrier of Lake Whittlesey.

All of the facts displayed in the Black River valley are completely in harmony and are in perfect accord with the idea that the Arkona beaches were made first and extended northward around the "thumb" into the Saginaw basin, and that the ice sheet then readvanced to the position of the main moraine of the Port Huron system, destroying the Arkona beaches on the "thumb," drowning all those south and east of it, and causing the formation of Lake Whittlesey

and the building of the Whittlesey beach. Where the Arkona beaches were protected, as in the Black River valley, they were preserved; where they were exposed, as south of Spring Hill, they were destroyed.

One of the remarkable features of this area is the small amount of outwash that issued from the moraine. A moderate amount spread along the front of the moraine as far south as Amadore, probably burying the upper two beaches beyond their observed terminations; but south of Amadore the lower Arkona beach, though actually in contact with the foot of the moraine, appears to bear not the slightest particle of silt or sand or clay—to bear no outwash whatever. Such a condition is extremely hard to explain, for it would seem certain that dirty ice, such as carried the material of the moraine, would in melting produce muddy silty waters and deposit the sediment on the bottom, or it might build a sandy apron, as it did farther north. Possibly the movements of the water in the trough may give some explanation, although this seems doubtful. The waves that rolled up the valley might have kept the water along the ice sufficiently agitated to prevent the deposition of silts and clays, but it seems hardly possible that it could have prevented the deposition of sand. Another interesting evidence of the restricted efficiency of wave action in this valley is the fact that where the first and second Arkona beach ridges turn inward toward the axis of the valley, as they do in sec. 6, Grant Township, and secs. 31 and 30, Worth Township, they grow faint and flat, like those south of Spring Hill. The meaning of this seems to be that where the beaches run north and south in almost exact parallelism with the axis of the deeper water in the trough they were not effectively attacked by the waves, but where they turned diagonally across the valley axis they were exposed to an oscillating swing of the heavier seas and were partly washed away. Unless this is true, it is not easy to explain why these three beaches are strong and unmodified within a mile inside of the valley entrance at Spring Hill, while they are so greatly modified a mile or two outside.

In view of the narrowness of the entrance to Black River Bay of Lake Whittlesey and of the narrowness and rather small extent of the bay itself, it is surprising to find many of the Whittlesey bars and beaches within the bay so strongly developed. From their strength it might be thought that they were formed before the ice front had advanced to the place of the main moraine of the Port Huron system. But the beach forms, which were studied in unusual detail in this area, show conclusively that this was not the case, or at least was so in only very slight degree, for the Whittlesey beaches in the bay show strong predominance of wave action from the south and southeast; that is, from the direction of the mouth of the bay and by deflection over the shallower part from the deeper trough along the east side. The submerged Arkona beaches show a different relation. (See pp. 369–370.)

WHITTLESEY BEACH IN OHIO, PENNSYLVANIA, AND NEW YORK.

Mr. Leverett[1] has described the Whittlesey beach in Ohio, Pennsylvania, and New York in considerable detail, and it is necessary to refer here only to slight changes in his conclusions suggested at one or two localities in Ohio by the new topographic maps, and in New York and Ontario by recent field work done by the writer.

In northeast Palmer Township (secs. 1, 2, and 3) and northwest Liberty Township (secs. 6, 7, 8, and 17), Putnam County, Ohio, there is a fragmentary beach which Mr. Leverett had regarded as belonging to the Whittlesey (Belmore), but which, as shown by the altitudes on the topographic map (Ottawa quadrangle) recently made of this district, is probably the lowest beach of Lake Maumee. The Whittlesey beach in all probability lies 1 to 2 miles farther west and more nearly in a direct line from Pleasant Bend to Ottawa.

Similarly, a beach running northwest from North Monroeville, Ohio, proves to be the lowest beach of Lake Maumee instead of the Whittlesey (Belmore) beach as shown by Mr. Leverett,[2] though the bar that runs north from this place and crosses the New York, Chicago & St. Louis Railroad does belong to the Whittlesey shore.

[1] Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 747–757.

[2] Idem, Pl. XXII.

In July, 1905, H. L. Fairchild and the writer made some detailed studies on beaches and related moraines in the critical area between Hamburg and Alden, N. Y. Among other things the writer recognized very faint marks of the Whittlesey beach for a mile or two north of Marilla, 905 to 910 feet above sea level, the altitude of the upper Arkona beach less than a mile to the northwest being 850 feet. These fragments are extremely faint, but they evidently belong to the Whittlesey beach, for they are only 3 miles northeast of stronger fragments previously recognized and lie in the plane of the Whittlesey beach produced from the southwest.

WHITTLESEY BEACH IN ONTARIO.

In Ontario the Whittlesey beach (Spencer's Ridgeway beach) runs irregularly from Komoka northward to Lucan crossing and thence directly north to a fading termination south of Clinton. From Komoka it runs eastward to about 10 miles south of London and thence somewhat crookedly to a little north of Waterford, where it turns directly north, passing west of Brantford and thence northeastward in fading strength toward Georgetown. Northward from London it was traced by the writer, eastward by Spencer.

ALTITUDE OF THE BEACHES.

In the area of horizontality, the Whittlesey beach, wherever found in average strength and development as a beach ridge, lies about 735 to 740 feet above sea level. Northeast of Birmingham, Mich., however, it begins to rise northward in common with the Maumee, Arkona, and Warren beaches at the rate of about 1 foot to the mile. At Richmond its altitude is about 751 feet. Spencer made its altitude 770 feet 3 miles east of Emmett, but this is undoubtedly 10 to 15 feet too high. On the great spit at Spring Hill its altitude is about 765 feet and on some of the strong bars west of Applegate about 775 feet. At Ubly, in the head of the outlet, no distinct mark of a water level is visible, but the gravel bars in the upper part of the outlet channel seem to suggest about 10 feet of water, and the level of the floor in the head of the outlet at Ubly is about 800 feet above tide, making the level of Lake Whittlesey at the head of the outlet close to 810 feet. These measurements are all by aneroid.

In Ohio Mr. Leverett finds from the new topographic sheets that the Whittlesey beach on the front or west side of the Defiance moraine stands pretty generally at 740 to 743 feet altitude but is a trifle lower—735 to 740 feet—on the inner or east side. This slight difference is thought to be due to the greater strength of the westerly winds.

Mr. Leverett[1] remarks that "the altitude of the beach has very little variation from the Maumee River near Defiance eastward to Ashtabula, Ohio, a distance of 200 miles, the lowest measured altitude being 731 feet and the highest 742 feet above tide." At the Ohio-Pennsylvania State line the Whittlesey beach has an altitude of 746 feet, which is 6 or 8 feet higher than in the area of horizontality. It rises at first gradually, but soon attains a rate of more than 1 foot a mile, being 772 feet at Erie, 785 feet at the New York-Pennsylvania line, a little above 800 at Westfield, a little above 820 at Dunkirk, 840 at Hanover Center, 850 at North Collins, 890 near Elma station, and a little above 900 feet at Marilla. Thus, from the Ohio-Pennsylvania line to Marilla, N. Y., a straight-line distance of 125 miles, it rises about 155 feet.

Near Applegate, Mich., it stands about 30 feet above the uppermost of the three strong Arkona beaches, in the Ann Arbor quadrangle about 32 feet above the same beach, and at Marilla about 55 feet above it. It was observed in the field that the Arkona beaches are much better preserved and show less modification in New York State, especially east of the Cattaraugus Valley than in what appear to be equally exposed situations in Ohio and Michigan. Northeastward from Hamburg this is no doubt partly accounted for by the narrowness of the waters between the ice front and the land, affording a measure of protection, like that in the Black River valley. But it is also due in part to the wider vertical interval between the Whittlesey and upper Arkona beaches and the consequent greater depth of submergence, which reduced the power of the Whittlesey waves. This consideration applies especially to the beaches in New York southwest from Hamburg.

[1] Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 755–756.

DISTINGUISHING CHARACTERISTICS.

In general the Whittlesey beach is remarkable for the height to which it is built above the plain in front of it and for the boldness of its slope both in front and rear. It is generally composed of gravel, with a rather large proportion of sand, and everywhere, excepting in connection with certain delta deposits, it is remarkable for the singleness of its form. In many places the steepness of the beach in front along its base suggests the idea that it has been slightly undercut by wave action since it was made, but no other evidence of such undercutting was found. If such had occurred it would be expected to produce constructive forms in some localities, but nothing of this kind has been observed except beach A (see p. 369), which is probably of different origin.

The manner in which Lake Whittlesey came into existence (by readvance of the ice and raising of the water level) explains certain characters which mark this beach more strongly than any other that has been found. Its course across the country is remarkably direct in view of its many crossings of river and creek valleys, which appear to have been excavated to approximately their present depths before this beach was made. It crosses these in a direct line, like a railroad embankment, in places standing 20 to 25 feet above the valley floor at its back.

It is significant, in the first place, that the river and creek valleys were eroded out to such an extent before this beach was made. This shows clearly that the lake level and consequently the base-level of erosion were for a considerable time lower than Lake Whittlesey before that lake came into existence. This would naturally have been the case during the time of Lake Arkona, for the streams during all the period of that lake at its different stages were cutting down to it as a base-level. When Lake Whittlesey was subsequently raised to a higher level, it found these stream valleys already carved apparently to nearly their present proportions.

Some other beaches show clear evidence of weak or short-lived wave action at the back of bays or reentrants of their shores which were subsequently cut off by spits or bars built at the same stage of the lake. Such a relation indicates that the faint beach at the back of the bay was built before the shore currents had projected the spit across the front of the depression.

This, however, is not the case with the Whittlesey beach at any locality observed. Not the slightest evidence of wave action appears at its level in embayments at its rear. This fact and its extraordinary height and boldness suggest that it was built rapidly and was pushed a few feet up the slope while it was being built, so that the back shore of the bays closed by barriers was never exposed to wave action at the level at which the beach was made.

The supply of material for building the ridge seems to have been uncommonly plentiful and easy of access by the storm waves. This, again, would naturally be true for Lake Whittlesey, because the greater bulk of the gravel in the Arkona ridges was torn away and swept up the slope by the storm waves. Such conditions would be especially favorable for the production of just such characters as are found in the Whittlesey beach.

The head of the outlet of Lake Whittlesey is a broad flat with two openings across a low divide. The one at Tyre is floored with nearly horizontal beds of sandstone. It seems quite likely that as the moraine pushed up the slope from the north the outlet had this sandstone for its sill for some time before the final halt of the advancing ice. If that were true it is easy to see how the level of the lake was gradually raised in the last stages of advance and the beach pushed a few feet up the slope. This may be true, although it seems also true that the first raising of the waters when the ice began to advance was relatively rapid. It appears at least to have been sufficiently rapid for the Arkona beach ridges a mile northeast of Spring Hill to have escaped modification in any perceptible degree by the waves, which would certainly not have been the case if the lake level had rested for any length of time in such a position that the surf would strike them. The truth of this statement does not in any way conflict with the conclusion previously stated that the storm waves running up the Black River valley lengthwise of the Arkona ridges apparently had no effect in modifying them, for this was when the beaches were submerged to a considerable depth and not exposed to the direct action of the surf.

The facts seem to indicate that the first 25 or 30 feet of rise of Lake Whittlesey was comparatively rapid and that the last 10 feet was more or less slow. When the Arkona ridges became submerged and the storm waves of Lake Whittlesey began to run over them with such force as to tear away the material of which they were composed, the building of the Whittlesey beach became correspondingly rapid.

It is thus apparent that the distinguishing characteristics of the Whittlesey beach are in close accord with the history and manner of origin of this lake. They are all such as are accounted for by the raising of the lake level from the Arkona levels, which were 30 to 45 feet lower and at which the waters had stood for a relatively long time and had built three strong gravelly beach ridges and deltas of corresponding strength.

Other lakes, Lake Maumee for instance, gathered nearly all their beach material by surf erosion of the bottom along the shore, but none of them seem to have done so on the scale of Lake Whittlesey. The writer does not recall any place in Michigan or in Ohio west of Cleveland where the Whittlesey shore line has formed a notable shore cliff. There seems to have been such an abundance of material that the waves were always doing constructive rather than destructive work at the water line. East of Cleveland the steepness of the lakeward slope was much more favorable to the formation of shore cliffs, and some were formed between Cleveland and Marilla.

DELTAS.

One of the exceptional characteristics of the shores of Lake Whittlesey is their general lack of deltas of the ordinary type. Of course, the streams that entered this lake must have carried on substantially the same work of erosion and deposition as in the preceding and succeeding lake stages, but the Whittlesey shores show almost no suggestion of the delta deposits that predominate all along the shores of Lakes Maumee and Arkona.

Some prominent delta deposits, such as those on Huron River just east of Ypsilanti, on Rouge River at Plymouth, and on Clinton River below Rochester, seem at first sight to be correlatives of the Whittlesey beach. But these deposits have been found to belong to Lake Maumee, mainly to its lowest stage. The delta of Lake Maumee east of Ypsilanti has old distributaries which belong to Lake Maumee and are too high to have served at the time of Lake Whittlesey. In fact, the Whittlesey beach skirts along the front of the Maumee deltas without showing any notable protruding deposit belonging to its own time.

The explanation seems to be that the valleys of the rivers were deepened and widened during the time of Lake Arkona when the rivers were cutting to that lake as a base-level. Then when the waters were raised to the Whittlesey beach by the readvance of the ice the lower courses of all the streams were drowned and turned into dead-water estuaries. It follows that at the beginning of Lake Whittlesey delta building began at the head of these estuaries and grew lakeward, reaching the open shore of the lake only when the estuaries had been completely filled. Thus the deltas of Lake Whittlesey are mainly inset or built within the old estuaries back of the general shore line and hence formed little or no protrusions at the shore. Since that time the streams have again cut down their beds and have carried away the main body of their estuarine deltas. Fragments of those deltas now remain along the sides of the valleys back of the Whittlesey beach as gravel terraces and are prominent in some places. They are well developed along Huron River in and below Ypsilanti. The sharply depressed, swampy little valley west of Armada was made in the Arkona stage of the lake and was not refilled, its stream being spring fed and having a very small drainage area and no flood stages to carry coarse sediments.

In eastern Ohio along the base of the escarpment and in western New York there are several delta deposits that seem to be closely related to the Whittlesey beach, but, as in Michigan, they probably belong to an earlier lake stage at a slightly higher level. In New York there is one delta, however, which is clearly a deposit in Lake Whittlesey, for it buries the eastward ends of the Arkona beach ridges a mile or two east of Alden. The river which built this delta flowed westward along the front of the ice when the front was on the Alden moraine. It flowed in a valley which had not been deepened during the time of Lake Arkona, and it is therefore an

exception to the inset deltas of Lake Whittlesey. This delta is not large, but its relation to the Arkona beaches establishes the time at which it was built.

In Ontario there are three Whittlesey deltas, each larger than any on the American side. One appears on Grand River between Paris and Brantford, another on Thames River between Komoka and London, and another on a large glacial river which came from the northeast along the ice front and entered the Au Sable Bay of Lake Whittlesey a few miles northwest of Clinton. The first two are inset deltas like those in Michigan. The third, like the one near Alden, N. Y., was built by a river flowing along the ice border. Another smaller delta, formed, like the last, by a river flowing along the ice border, occurs near Guelph Junction, Ontario. The fourth and only other place where such a delta could occur is occupied by the Ubly outlet in Michigan.

GLACIAL BARRIERS.

The positions of the ice barriers which retained Lake Whittlesey are more precisely and more completely known than for any other of the larger glacial lakes. The position of the ice front has been traced continuously, with the exception of one short interval, from the east side of Lake Michigan near Muskegon to the Genesee Valley in western New York. The interval remaining untraced lies along the Niagara escarpment south of Collingwood, Ontario. This untraced interval, however, does not affect the identity of the barrier in New York, because the moraine, which is clearly correlated with the Arkona and Whittlesey beaches near Alden, N. Y., has been traced westward through the Niagara Peninsula in Canada and around the west end of Lake Ontario, so that this part has been independently identified as belonging to the same line. On the Lake Michigan slope the Port Huron morainic system appears to be represented by three rather widely deployed ridges which reach the lake shore at Muskegon, Pentwater, and Manistee. The Muskegon ridge appears to be the correlative of the front part of the Port Huron system on the "thumb," and the correlative on the west side of Lake Michigan seems clearly to be a moraine which comes down to the lake shore at Milwaukee, Wis. The position of the western barrier of Lake Whittlesey is shown on figure 6 (p. 370) and a part of it on the east side of the "thumb" is shown in more detail on figure 5 (p. 366).

Since the early days of glacial studies in the Great Lakes region it has naturally been regarded as a desideratum of the first order to trace a single position of the ice front through the longest possible distance, and if possible to determine its position entirely across the Great Lakes region at one or more of its pauses. Except for the basin of Lake Superior, this result has been accomplished only in the determination of the ice barriers of Lake Whittlesey and the continuation of the same ice front, without a break, to the barriers of Lakes Saginaw and Chicago. Some of the earlier positions of the ice front have been almost as fully made out, but none later than Lake Whittlesey have been traced for anything like such a distance continuously.

Some years ago the writer[1] conjecturally showed the eastern ice barrier of Lake Whittlesey as running from Alden a little north of west along the south side of Grand Island to the west bank at Niagara Falls, and thence along the edge of the escarpment to Hamilton, Ontario. Later studies,[2] however, have proved that the line of the barrier passes west-southwest from Alden in a broad curve past Elma, Ebenezer, and West Seneca, and thence westward across the northeast end of Lake Erie to the Canadian shore at Crystal Bay. Thence it runs in very faint form parallel with the shore about 2 miles inland to a point north of Low Banks, and thence northwest to a point near Copetown, where it turns around the west end of the Lake Ontario basin and runs northward to Limehouse. Here it drops below the escarpment.

The moraines which mark the barriers of Lakes Whittlesey and Saginaw were water-laid and in their mid-valley parts, where the water was deepest, are extremely faint. The one at the east is faintest, being scarcely traceable for a part of the distance, except by its control of the minor drainage. The line of the barrier of Lake Chicago is now deeply submerged.

In character the two moraines which mark the eastern and western barriers of Lake Whittlesey are distinctly different. The Port Huron morainic system is of the major class, whereas

[1] Mon. U. S. Geol. Survey, vol. 41, 1902, Pl. XXIII.

[2] Niagara folio (No. 190), Geol. Atlas U. S., U. S. Geol. Survey, 1913, diagrams, pp. 17-18; also Trans. Canadian Inst., vol. 10, 1913, map.

its most distinct correlative, the Alden moraine in western New York, seems to be of minor rank. The Port Huron is a bulky, compound moraine made up of several ridges piled together, whereas the Alden ridge is single and slender, quite like one of the component ridges of the Port Huron system. Such a correlation raises some interesting questions as to the different characters of movements of the ice front at the same time at widely separated places. The Alden ridge is in all probability the correlative of one of the later component ridges of the Port Huron system on the "thumb" in Michigan.

The manner of the modification of the Arkona beaches, in Michigan especially, suggests a rapid rise of the lake at first with slower rise toward the climax or highest level. This accords well with the supposition that the front stood at least 25 miles back of the Port Huron morainic system during Lake Arkona. It would seem certain that the beginning of a movement of readvance after a backstep halt would be slow at first and would become most rapid in the middle part of the advancing movement, slackening again toward the forward climax. From these theoretical considerations, which are based on the periodic, oscillatory nature of the movements, it is not surprising to find that the beginning of the readvance to the Port Huron morainic system did not affect the level of Lake Arkona but only made narrower the strait that led past the end of the "thumb" to Lake Saginaw. It was only when the movement of readvance was going forward at its most rapid rate and had covered perhaps more than half of its whole interval that it suddenly closed the strait, and the waters east of the "thumb" began to rise to higher levels. Toward the climax of readvance the rate of forward movement became slow, and the last few feet of rise was gradual. The facts seem to bear out fully this interpretation of the manner, rate, and amount of readvance. The recession of the waters must have been still more rapid, for if the glacial oscillations were periodic and superposed on a general movement of retreat the backsteps were always longer than the foresteps in distance, though equal in time. Hence, in the oscillations the maximum rate of recession was always inclined to be more rapid than the maximum rate of readvance.

CORRELATIVES OF LAKE WHITTLESEY.

During the time of Lake Whittlesey Lake Saginaw was an independent lake (see p. 359), and after receiving the overflow of Lake Whittlesey it discharged into Lake Chicago, which had then attained hardly half its greatest extent. Two small narrow lakes probably stood in front of the Green Bay ice lobe, but according to Mr. Leverett there was still free drainage and no lakes at the west end of the Lake Superior basin. In New York Fairchild finds Lake Newberry to be the correlative of Lake Whittlesey, but Lake Newberry discharged southward to Susquehanna River. A river of some size entered Lake Whittlesey northeast of Alden, N. Y., and built a delta which buried the Arkona beaches.

TRANSITORY LATER LAKE ARKONA.

In falling from the level of Lake Whittlesey to that of Lake Wayne the water level necessarily passed the planes at which it had stood in making the Arkona beaches, and Lake Arkona was temporarily revived. But this relation was transitory and endured for so short a time that no evidence of renewed wave work has been found.

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CHAPTER XVIII.

GLACIAL LAKE WAYNE.

By Frank B. Taylor.

HISTORY.

When the waters fell from the level of Lake Whittlesey they passed the levels which they had formerly held at the Arkona beaches rapidly and apparently made their first important pause, not at the Warren beach, which is the first strong beach below the Arkona beaches, but at a lower beach of a lake here called Lake Wayne, after the place where its beach was first observed in strong development.[1]

The Wayne beach is below the level of the Warren but appears to be the older of the two, for it shows clear evidence of submergence and modification, and the Warren beach does not. It seems, therefore, that the Wayne beach was submerged and modified during the time of Lake Warren.

The Grassmere and Lundy (Dana, Elkton) beaches are not included with the Wayne, for they show no evidence of submergence and were made after the Warren in the transition to Lake Algonquin. Nevertheless, the lowest stage of Lake Wayne may possibly have coincided with the phase later reached by the earliest stage of Lake Algonquin, for it is not known how low the Wayne waters fell before they rose to form Lake Warren.

OUTLET.

The place of the outlet for Lake Wayne has not been certainly fixed by continuous tracing, but it is almost certain that it was eastward to the Mohawk Valley through some of the channels south of Syracuse, N. Y., for the Wayne beach is slightly lower than the head of the Grand River channel. It is possible, but not probable, however, that the lake found an outlet northwestward along the base of the high ground to Lake Chicago near Little Traverse Bay. (See p. 391.)

WAYNE BEACH.

DISTRIBUTION.

MICHIGAN.

In Michigan the Wayne beach has usually been called the "Lower Forest" or "Lower Warren" beach, but since its character as a submerged beach has been recognized, these names have become peculiarly inappropriate. The beach is well developed at the village of Wayne, in Wayne County, Mich., and the name of that place is given to it.

From the Ohio-Michigan line to the south bank of Black River northwest of Port Huron this beach is generally developed in considerable strength, but through most of the interval it is either composed of fine, partly wind-blown sand or is buried and obscured by it and is thus somewhat lacking in sharpness. At several places it lies in the heavy sandy belt of the region and in such places is hard to follow.

Monroe County.—The Wayne beach enters Michigan 2 or 3 miles northeast of Sylvania, Ohio, as part of the broad, sandy belt which Gilbert[2] called the fourth beach. The sandy belt is about 6 miles wide at the State line and runs northward across the central part of Monroe County.

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[1] The position of the ice barriers of Lake Wayne is not accurately known, but they were presumably a little farther back toward the north than those of Lake Warren. (See Pl. XVII, p. 392.)

[2] Geological Survey of Ohio, vol. 2, 1874, pp. 49-50, map facing p. 56.

From the southwest corner of Bedford Township the Wayne beach runs as a rather indefinite ridge in the sandy belt northward past Lambertville, passing about a mile east of Lulu and Federman and a mile west of Raisinville. A mile north of Raisin River it enters the area covered by the Survey's recent topographic maps.

This sandy belt and one or two others are well shown on Sherzer's map of Monroe County,[1] but the names he uses are not in accord with the established usage farther north. In the area of horizontality the Wayne beach has an altitude of about 660 feet, in places reaching 665 feet. The beach which Sherzer calls the Forest (Warren) beach corresponds to the Wayne beach here described, the Warren being a few miles farther west.

Washtenaw County.—In the Ypsilanti quadrangle the course of the Wayne beach is well marked along or slightly above the contour line of 660 feet. The wind-blown character of the belt is partly expressed on the Survey map by the ragged line along this contour and by small, patchy areas which mark dunes with swampy hollows between them.

Wayne County.—In the Romulus quadrangle the Wayne beach passes just west of Martinsville and north of French Landing and Romulus. It includes well-marked delta deposits at Huron River near Romulus.

From Romulus the Wayne beach runs directly north for 10 or 12 miles and is generally well defined. At the village of Wayne it is a ridge of sandy gravel 15 to 20 rods wide and standing 10 to 12 feet above the plain east of it and 5 to 6 feet above that west of it. It continues strong past Livonia, thence turning gradually northeast and east to the edge of the Detroit quadrangle.

Entering the Detroit quadrangle the Wayne beach swings sharply to the southeast for about 6 miles, and in sec. 17, Greenfield Township, it makes a rather sharp turn north to Royal Oak. This wide detour is caused by the Detroit interlobate moraine and shows remarkably well the trend of this feature.

Oakland County—Near Clawson, 3 miles north of Royal Oak, the beach splits up into three or four heavy sand bars which run parallel toward the south. Royal Oak is on the eastern ridge. Southwest of the village the bars bend southwest on spreading lines and include Hubbard Marsh and one or two others between them. The whole formation in this quadrangle is sandy and considerably wind blown.

In the Rochester quadrangle the Wayne beach is not strong, but is more generally gravelly and better defined. It curves gradually eastward from Big Beaver and passes less than a mile north of Utica. From this place it leads northward, running half a mile east of Disco and thence northeast out of the quadrangle 2 miles east of Washington.

Macomb County.—In Ray Township the Wayne beach is developed in considerable strength, but is sandy at most places. It passes three-fourths mile west of Ray Center and runs northeast into Lenox Township, in the northwestern part of which it is sandy in places but has gravel and bowlders also associated with it. In the western part of the township it appears as isolated gravel bars on morainic knolls. East of this for 2 or 3 miles it is represented only by bowldery ground with a few little low sandy bars.

St. Clair County.—From the delta at Columbus the Wayne beach runs directly north-northeast past Hickey, where it is a well-formed gravel ridge, to Thornton, where it broadens into a sandy delta of Pine River. From this it continues northeast for about 3 miles as a pair of sandy ridges which die out in an extensive sandy plain. It is well developed and is composed of sandy gravel nearly to Thornton. A very light and broken little ridge of gravel runs about halfway between it and the Warren beach throughout this interval, and it splits slightly for about 4 miles south of Thornton.

Four heavy lines of dunes running north and south on the back of the water-laid part of the Port Huron morainic system west and southwest of Port Huron appear to belong mainly to the Wayne stage of the lake, the surface of the moraine being barely submerged at that time. But they may belong partly to the Grassmere stage, for some of them are low enough for that beach.

[1] Geological report on Monroe County, Mich.: Michigan Geol. Survey, vol. 7, pt. 1, Pl. VII, p. 112.

Immediately on crossing to the north side of Black River the character of the country changes. Sandy plains are absent, excepting one that reaches 4 or 5 miles northwest from Port Huron and one that stretches a few miles along the shore between Port Huron and Lakeport. The beaches are mainly gravelly, though in places sandy, especially where they merge into the deltas of small streams. The ground between the beaches is mainly stony or sandy till and is sprinkled in many places with stones and bowlders.

In northeastern St. Clair County, west from Lakeport, the Algonquin, Lundy (Elkton), and Grassmere beaches are all clearly developed. But between the Grassmere and Warren there is a flatter strip about 2 miles wide in which there is no certain evidence of a beach except a faint, washed-down, fragmentary line that lies close to and 20 to 25 feet below the Warren and that may represent the Wayne beach. For about 14 miles it is not over one-quarter to one-eighth of a mile east of the Warren. It is generally composed of gravel with some stones and is low and irregular. In many places it is broken and apparently missing, and by contrast with the Warren beach it is very faint. At first it seemed doubtful whether this beach is the same as the Wayne beach farther south, where the latter stands so clearly apart from the Warren. But north of Black River the lakeward slope is much steeper and the beaches are set closer together. Measured by vertical interval, this faint beach stands about the same distance below the Warren that the Wayne does farther south.

Sanilac County.—The beaches along the lakeward slope of Sanilac County to the south line of Huron County were studied in considerable detail a number of years ago when the real character of the Wayne beach was not understood and the lake history itself had not been so fully worked out as now. All the beaches in this area were followed northward with almost entire continuity, except where they had been cut away along the present shore. In going northward and rising to higher levels some of the beaches, particularly the Grassmere and in somewhat less degree the Lundy (Dana, Elkton), split up into several slender beaches. The Wayne and Warren beaches also show some splitting, but it is inconspicuous and is probably of different origin and significance from that of the other beaches. (See p. 405.) At the north line of Sanilac County the Wayne beach appears to split into three or four slender strands with not over 10 feet difference in altitude for the whole interval. Such a range is no more than is common in many beaches. It may be due to seasonal variations, to erosion of outlet, or perhaps in some places to distant ice attraction and does not necessarily imply uplift.

It is to be noted also that the Wayne beach keeps its place close to the Warren, the series lying 25 to 35 feet below the upper strand of the Warren. This constancy of interval shows that no important tilting of the land took place between the making of the Wayne and Warren beaches.

The beaches below the Wayne were traced continuously through Sanilac County and were found to show no tendency to confusion with the Wayne. In fact the widest and most distinct space separating the beaches on this slope is between the Wayne and the Grassmere, and it is just as clear where the splitting occurs as elsewhere. The Warren is distinctly double all through the region of the "thumb" and the faint Wayne beach lies below its lower member. The writer's studies, however, were not detailed enough to distinguish positively between the lower member of the Warren and the highest faint member of the Wayne in northern Sanilac County. The mapping as it now stands seems to show some confusion, and further detailed study is needed.

Huron County.—In Huron County the beaches between the Warren and the Algonquin have not been traced continuously, although they have been crossed on three or four different lines. A beach in northwest sec. 6, Sigel Township, 3½ miles north of Verona Mills, has an altitude of about 750 feet and is probably the Wayne or one of its strands. Two miles northwest of Bad Axe a rather wide gravelly belt is in all probability the Wayne beach. A mile north of Popple there is a delta that seems to belong to this beach. The beach is very distinct, though "washed down," from Rescue to Gagetown.

Tuscola County.—In Tuscola County the Wayne beach was followed from 3 miles east of Fair Grove southwest to about 2 miles northwest of Vassar. In this interval the beach has its usual weak, washed-down appearance and is in some parts hard to follow. In this stretch it is

distinctly double; at Denmark its upper member is about a quarter of a mile east of the corner and its lower member a few rods west of it.

Saginaw Valley.—The Saginaw Valley south and west of Cass and Tittabawassee rivers is very generally sandy at the level of this beach and the sand is fine and considerably wind blown. The Wayne beach has not been certainly identified in this area. Northern Bay County and Arenac and Iosco counties are of much the same sandy character below the Warren level. In these counties occasional fragments thought to belong to this beach were observed some years ago, but no continuous tracing was done. This beach, like the Warren, Grassmere, and Lundy (Dana, Elkton) beaches, seems to end near Au Sable River in Iosco County.

OHIO, PENNSYLVANIA, AND NEW YORK.

In Ohio and in States farther east no systematic search for the Wayne beach has been made. West of Toledo it is part of the wide sandy belt which Gilbert designates the fourth beach. Mr. Leverett and the writer found a sandy and gravelly belt near Sandusky and Huron, which from its altitude seemed to correspond to the Wayne beach. A sandy belt close below the Warren beach, seen by the writer in 1905 at a number of places along the escarpment eastward from Cleveland into Pennsylvania and western New York, probably belongs to the Wayne but has not been the subject of particular study. Northeastward from the Cattaraugas Valley, in western New York, the level at which the Wayne beach would be expected shows, so far as known, almost nothing suggesting it. Only a few fragmentary gravel ridges have been found, like the bar that runs about 3 miles west from Eden and the Cooper ridge which takes a remarkably sinuous course north and west of Hamburg. It is not certain, however, that these ridges represent the Wayne beach, although they occur about at the level at which it might be expected. They may correspond to the Grassmere beach of Michigan.

ONTARIO.

Spencer makes no certain mention of this beach in Ontario, or of anything that might correspond to it. The writer carefully examined the slope between Forest and the present lake shore but found no sign of it, yet Spencer's Forest (Warren) beach is strongly developed at Forest, which is its type or name locality.

An indefinite stony belt seems to represent the Wayne beach just east of Mandaumin, where its altitude is about 650 feet. At a number of other places a faint sandy or gravelly belt corresponding to this beach was seen, especially near Chatham, Ridgetown, and Blenheim, and between Port Rowan and Simcoe.

CHARACTER OF THE WAYNE BEACH.

In Michigan, between Port Huron and Toledo and also in the sandy areas of the Saginaw Valley, the Wayne beach is very sandy and is generally poorly defined. The sands have been blown by the wind extensively. This beach also merges now and then into broader sandy areas that in some places appear to be outwash and in others sandy deltas. On this account the beach seems very wide in some places and broken and missing in others, and the action of the wind has in places reduced it to scattered patches of sand.

In these sandy districts nothing was found that showed decisively that the Wayne beach had been submerged. But on the "thumb," north of Black River on the east side and north of Cass River on the west side, the Wayne beach shows clear evidence of having been submerged and greatly modified. On the "thumb" it is almost everywhere a gravel belt or low ridge similar to the third beach of Lake Maumee and the Arkona beaches southwest of Spring Hill. It is strongly developed in few places and in many it is so faint as a surface feature that it might easily be overlooked. Where fairly well developed it is peculiarly flat and broad and very unlike the usual type of gravelly beach ridges which have not been submerged.

In western New York and at Forest, Ontario, where the northwest exposure favored strong wave work and the development of gravelly rather than sandy shore accumulations, the Wayne beach seems either absent or almost totally destroyed.

The deltas of Lake Wayne do not protrude so far into the lake bed as do those of the earlier submerged stages, and it would hardly be expected that they would, for the Wayne beach is farther from the high ground and the streams naturally brought less gravel to it. Waves and shore currents distribute fine sand more easily than gravel, and deltas of sand are not so likely to protrude where the stream enters on a rectilinear shore.

The delta of Huron River at the time of the Wayne beach is south of Romulus and shows well-marked protrusion for a mile or more on both sides of the river. This deposit, however, is largely coarse sand and fine gravel.

Other deltas associated with the Wayne beach show less protrusion. On Clinton River at Utica the earlier delta of Lake Arkona protrudes very strongly, and the stream issues from the apex of the older deposit. On this account the sediments brought down later were exposed to powerful currents from the southwest and from the north and in consequence were constantly swept away, mainly to the north, and built into spits and bars that run northward into the depression north of Disco. A smaller quantity was carried to the southwest. These features near Utica are shown on the map of the Rochester quadrangle.

In strong contrast, the Warren (Forest) beach, which lies 20 or 25 feet above the Wayne, is strongly developed and sharply defined wherever it is composed of gravel and, like the Whittlesey beach, which it resembles in many ways, shows no evidence of modification by submergence.

RELATION TO LAKE WARREN.

It is concluded, therefore, that the Wayne beach was made before the Warren, when the lake waters stood at a lower level, and that this beach was submerged under the waters of Lake Warren and was modified by the overpassing waves of that lake. The materials of the Wayne beach in the gravelly district especially were largely removed and swept up the slope to be built into the Warren beach.

Lake Wayne, therefore, preceded Lake Warren in the same way that Lake Arkona preceded Lake Whittlesey and the cause was probably the same, namely, a readvance of the ice front closing the outlet of Lake Wayne and raising the waters to the level of the Warren beach. There is thus added one more set of facts indicating oscillation and readvance of the ice front in the general retreat.

ALTITUDE OF WAYNE BEACH.

In the area of horizontality the Wayne beach has an altitude of about 660 feet, its crest being shown a little above the 660-foot contour on nearly all of the Survey's topographic sheets.

In the Rochester quadrangle it does not appear to begin to rise northeastward so soon as the Maumee beaches. Indeed, where it leaves the quadrangle 2 miles southeast of Washington its altitude is 663 feet or possibly 1 or 2 feet higher. A mile toward the southwest the crest of a light bar of this beach half a mile west of the main ridge has an altitude of 665 feet, not perceptibly higher than its altitude farther south. Even at Hickey, in St. Clair County, the altitude of the station is given as 660 feet and the crest of the beach is only 2 or 3 feet higher. The profiles of the Pere Marquette Railroad on both lines running out of Port Huron are, however, known to be less accurate than could be desired. Where the Port Austin branch crosses the Wayne beach in northeast sec. 11, Clyde Township, the altitude of the beach is between 670 and 685 feet, more accurate measurement not being available. The rise of the other beaches in this district is at first a foot or less per mile. Hickey is about 14 miles south of the point mentioned. The rise of the Wayne beach, therefore, probably begins not far north of Hickey. North of this to the north line of Sanilac County no reliable measurements of this beach are available. Several measurements by aneroid barometer were made, but they show so much discordance that they are probably not of much value. One mile from the north line of Sanilac County four faint strands which are thought to represent the Wayne beach were found by wye levels run by Mr. Leverett to have altitudes of 727.5, 722, 721, and 717.4 feet. A faint beach crossed by the railroad 2 miles north of Ruth at an altitude of about 740 feet is thought to be the Wayne,

but it may be the lower strand of the Warren, as the upper Warren near Ruth is 756 feet. About 3½ miles north of Verona Mills a beach thought to be the Wayne has an altitude of 745 to 750 feet. Two miles northwest of Bad Axe gravels thought to represent this beach have an altitude of 740 feet. Near Gagetown its altitude is about 720 feet. Northwest of Vassar its altitude is 685 or 690 feet.

This beach has not been identified with certainty at other points in Michigan or in the States farther east and its altitude has not been determined in those regions. Its relation to the pre-Algonquin uplift will be discussed in connection with Lake Lundy. (See pp. 405–406.)

GLACIAL BARRIERS OF LAKE WAYNE.

The location of the ice barriers of Lake Wayne has not been determined by observation and can only be inferred from the relations of the moraines and from the relations of Lake Wayne to Lake Warren and the early stage of Lake Algonquin. (See pp. 397, 407.)

It seems hardly possible that the Wayne beach marks the lowest altitude of Lake Wayne. In all probability there were lower stages and lower beaches that have not been found or have been destroyed. It is possible that at its lowest stage the lake stood as low as or lower than the Lundy (Dana, Elkton) beach. If it fell below the Lundy it was in all probability identical with the first stages of Lake Algonquin. Such a stage would be an isolated, transient development of the latter lake precisely like the early stage of Lake Algonquin described below, which came after Lake Warren.

About all that can be said concerning the barrier in the Lake Huron basin is that it stood a little farther back toward the northeast than the barriers of Lake Arkona and Lake Warren. (See fig. 6, p. 370.) The eastern barrier had a more critical relation to the lake waters, for it rested on the relatively steep northward slope of the country south of Syracuse, N. Y., where every oscillation of the ice front changed the altitude of the outlet and affected to a corresponding degree the level of the waters to the west. The position of the eastern barrier of Lake Whittlesey is accurately known, and that of Lake Warren is almost as well determined. Both of these lakes marked climaxes of readvance. Lake Arkona existed during a climax of retreat, but so far as known that retreat did not extend far enough to open an eastward outlet. Lake Wayne marked the next climax of retreat and apparently for the first time an eastward outlet was opened. On page 18 of the Niagara folio[1] a diagram shows the positions of the ice barriers of Lakes Whittlesey and Warren, and two conjectural positions for the first barrier of Lake Iroquois. Between the Niagara Falls moraine, which marks the barrier of Lake Warren, and the Carlton moraine, near the shore of Lake Ontario, there are two and probably three moraines—the Barre on the edge of the escarpment, the Albion just below it, and a moraine indicated by the morainic knolls in Newfane. All these moraines mark climaxes of readvance, but the readvance to the Barre moraine, following Lake Warren, did not restore the westward outlet; so it seems almost certain that the eastern barriers of both Lakes Arkona and Wayne stood only a few miles north of the Niagara Falls moraine, somewhere near the Barre or the Albion moraine.

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[1] Niagara folio (No. 190), Geol. Atlas U. S., U. S. Geol. Survey, 1913.

CHAPTER XIX.

GLACIAL LAKE WARREN.

By Frank B. Taylor.

LOCATION AND ORIGIN.

Lake Warren followed Lake Wayne and covered the basin of Lake Erie, a part of the south arm of Lake Huron, including Saginaw Bay and much of the lowland which separates Lake Huron from Lake Erie. It also included a small part of the Lake Ontario basin and most of the lowland between Lakes Ontario and Erie. It drained westward from Saginaw Bay through the Grand River channel to Lake Chicago. (See p. 360.) Lake Warren came into existence in the same manner as Lake Whittlesey; that is to say, its waters were raised from the level of Lake Wayne by a readvance of the ice which closed the outlet that had served for the lower stage. (See Pl. XVII.)

EARLIER INVESTIGATIONS.

Hubbard in 1839–40 made brief mention of the Warren beach in Michigan in the early geologic reports of the State, and Whittlesey noted it in Ohio in 1850–51. Other early observations on it were made by Gilbert in Ohio, Pennsylvania, and western New York, and by A. A. Wright in Ohio.[1] It was recognized as a "lake ridge" and was used as a highway at an early day in Michigan, Ohio, New York, and Ontario. Gilbert traced it in 1896 from Spencer's locality west of Port Huron to a point opposite Richmondville on the "thumb." Fairchild[2] observed it in New York in 1897 to a point some miles east of Genesee River, and recognized it provisionally to a point near Marcellus. Leverett[3] described it in 1902 in considerable detail from the Ohio-Michigan line to the vicinity of Indian Falls, N. Y., about 30 miles east of Buffalo. Spencer found it in Ontario and called it the Forest beach. He did not recognize it as the beach of a glacial lake, but as that of a sea which he called "Warren Water," and which he supposed to extend indefinitely to the north and northeast. Spencer made "Warren Water" cover the whole Great Lakes region but regarded it as marine. Lawson and Upham, following Spencer, gave it the same great extent but regarded it as a lake. The present more restricted use of the name was suggested by the writer[4] in 1897.

WARREN BEACH.

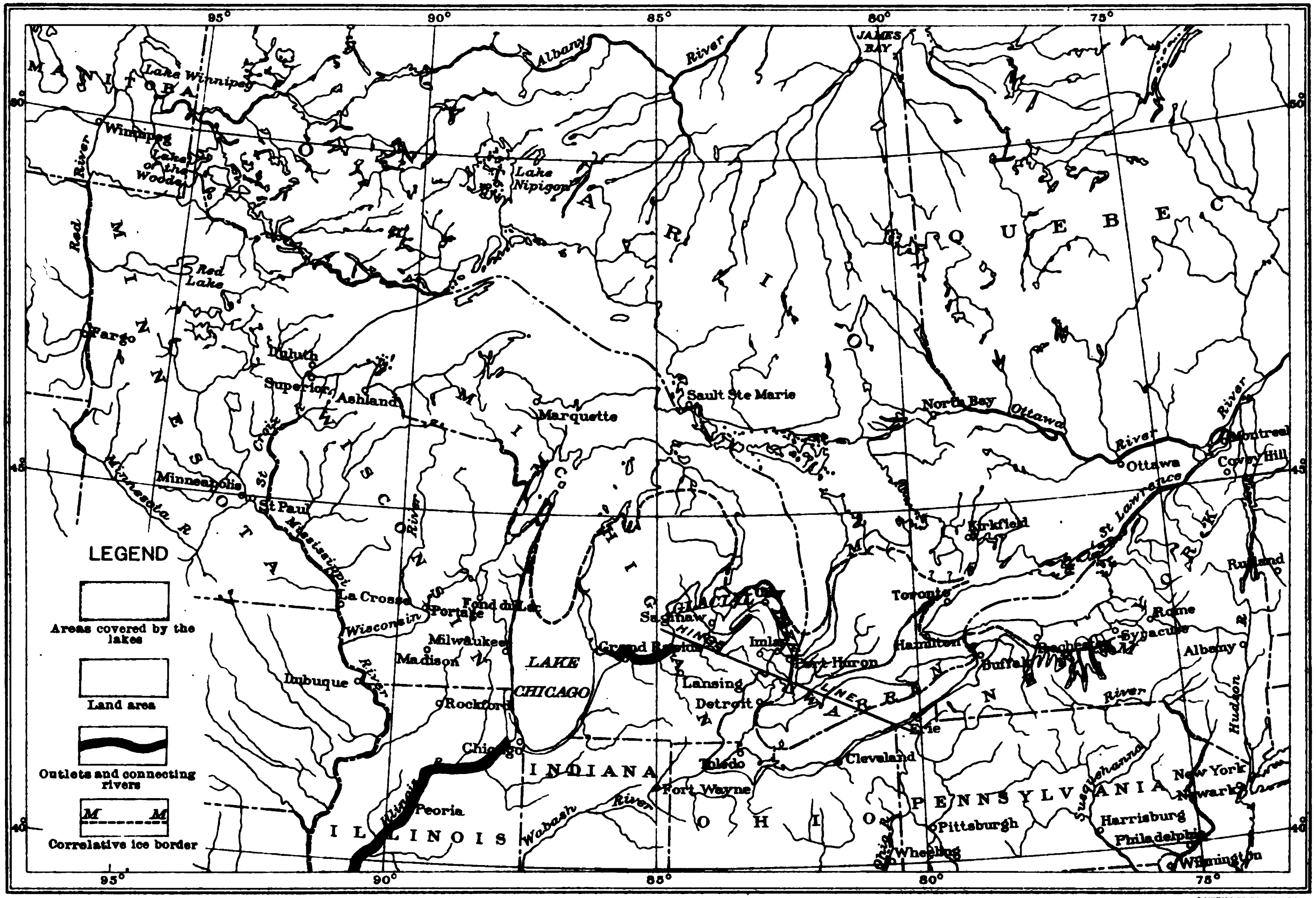
DISTRIBUTION.

MICHIGAN.

Monroe and Lenawee counties.—In Monroe and Wayne counties, Mich., the Warren (Forest) beach, which has there been studied chiefly by Sherzer, takes the form of a wide belt of sand generally fine in texture and in places considerably modified by the wind. It runs across a flat clay plain sloping toward Lake Erie at the rate of 5 to 10 feet to the mile.

The Warren beach constitutes a part of Gilbert's fourth beach in northwestern Ohio. At the State line in southwest Monroe County it is a sandy belt with some gravel, and it runs thence several miles northwest to the large sandy delta of Raisin River in Lenawee County. Thence northeastward it returns to Summerfield Township, Monroe County, fringing the delta

[1] Mon. U. S. Geol. Survey, vol. 41, 1902, p. 760.
[2] Bull. Geol. Soc. America, vol. 8, 1897, pp. 274–297; also vol. 10, 1899, pp. 27–68.
[3] Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 760–771.
[4] Correlation of Erie-Huron beaches with outlets and moraines of southeastern Michigan: Bull. Geol. Soc. America, vol. 8, 1897, pp. 56–57.



A HOEN & CO. BALTIMORE

By Frank B. Taylor and Frank Leverett

MAP OF GLACIAL LAKES WARREN AND CHICAGO

The Ice Barrier was similar to this for Glacial Lakes Arkona and Wayne but lay slightly farther north at time of Lake Wayne

100 0 100 200 300 Miles

1914

on the south side of the river nearly to Petersburg. Thence it runs north and, to a point 4 miles west of Dundee, is a fairly strong beach ridge of sandy gravel. About 3 miles farther north it turns northeastward and enters Washtenaw County in sec. 33, Milan Township.

Washtenaw and Wayne counties.—From this point the course of the beach can be readily followed on the Survey's topographic maps of the Ann Arbor, Ypsilanti, Romulus, Wayne, Detroit, and Rochester quadrangles to a point 2 miles northeast of Washington, Macomb County. It does not itself appear prominently on the maps but its course is nearly identical with that of the 680-foot contour. Commonly it lies just above this line, but in places a little below it. From west of Dundee to 1½ miles north of Azalia it is represented only by low irregular patches of sand. North of Azalia, however, it becomes more definite, running along the front of a gravelly delta plain belonging to Saline River. A low bluff stands at its back and a wide plain of fine sand stretches in its front to the southeast and east.

The weakness of the beach in this stretch is probably due to the wide shallows which lay in front of it. In the Ann Arbor quadrangle an offshore bar of Lake Warren extends from Oakville southward past London with an altitude of 670 to 675 feet, or somewhat higher than the Wayne beach 1 to 1½ miles farther east and a little lower than the average of the main Warren beach.

From Saline River northeast to Whittaker the beach is broken and not well developed. East of Whittaker a sandy bar runs south about 2 miles toward Oakville, as if to join the offshore bar at that place. Between Whittaker and Belleville the beach is fairly well developed along the front of an older delta of Huron River. Through most of the interval from Canton to Farmington Junction it is a well-formed beach ridge of gravel and follows close along the west side of the contour of 680 feet.

Oakland and Macomb counties.—The Warren beach bends more than a mile southeast in eastern Southfield Township on account of the broad low ridge of the Detroit interlobate moraine, but turns again sharply northeast and north as it leaves the Detroit quadrangle. The beach is well developed as a strong gravel ridge through most of the interval from Southfield to where it passes out of the Rochester quadrangle 2 miles northeast of Washington. It is a particularly strong gravelly ridge a mile northwest and north of Utica along the front of an older delta of Clinton River.

The Warren beach has an altitude of about 687 feet in the extreme northeast corner of the Rochester quadrangle. From this point it runs northeast, passing 1½ miles north of Ray Center, to the northeast corner of Ray Township where it turns a little south of east and runs to a point a mile south of Lenox.

In this interval the Warren beach is not so strongly developed as in some other parts. Through Ray and Lenox townships it consists generally of a rather lightly formed pair of gravelly ridges. At Lenox, in common with the Whittlesey and Arkona beaches, the Warren beach turns sharply north and in turning grows surprisingly faint (in fact almost disappears) for 1½ miles. In this gap the ridge is not replaced by a wave-cut bench; the ground is a little stony but offers no other suggestion of a shore line.

St. Clair County.—From a mile above the Grand Trunk Railway bridge over Belle River the beach runs nearly straight north-northeast to near Abbottsford. Through Wales and Clyde townships it is strong and for much of the way stands well above the country at its back, as well as above that in front. For a mile or two south of Pine River it is 20 to 25 feet high. Toward Abbottsford it forks into three broad, sandy, branch ridges which diverge for a mile or two toward the north and northeast.

This great barrier beach shuts off a considerable bay behind it, but was not formed until the lake had existed for some time. This fact is established by the existence of a bay-shore beach back of the main ridge. From sec. 34, Wales Township, a very much lighter gravelly shore line runs north at the same level as the main ridge and a half mile back of it. In sec. 10 it is broken and offset on a patch of stony ground, but resumes its course half a mile farther west and runs northeast and then north, passing just east of Goodells and Abbottsford stations to Mill Creek, north of which it turns east and dies out on the sandy plain.

This fainter back ridge might be thought to be an Arkona ridge lower than the rest, but its behavior after crossing to the north side of Mill Creek proves conclusively that it was made after the building of the main moraine of the Port Huron system. It shows no tendency to follow the Arkona ridges up the Black River valley. It must have been made before the great barrier beach was built and in a relatively short time, for it is rather weak.

The rugged, land-laid part of the main moraine of the Port Huron system comes down from the north and terminates in a remarkably sharp point in the southeast corner of sec. 27, Clyde Township. (See fig. 5, p. 366.) In all probability it formerly extended half a mile or more farther south or southeast. From this point the Warren beach runs almost directly north to the north line of St. Clair County. It has its usual tendency to a double form much of the way, but the two ridges are set close together and in few places differ more than 8 or 10 feet in height.

Sanilac County.—In Sanilac County the beach runs directly north to a point west of Port Sanilac and then a little west of north to Huron County. Its development in this interval is quite even, but its lakeward slope grows more gradual toward the north and its two ridges are separated by about a mile at the north line of the county. At Charleston, 2 miles south of the line, the upper ridge is one-quarter of a mile west of the village and the lower one in the village, the difference in altitude being about 10 feet. Possibly the lower ridge divides again, but the relations have not been fully worked out.

Huron County.—In Huron County the two ridges of the Warren beach run north-northwest, the upper passing 1 mile and the lower 2 miles east of Ruth, eastern Sigel Township. Both ridges are finely formed in this interval, but are not developed in great strength except at some places where streams pass through them. Their lack of strength in Sigel Township is probably due to the wide shallows to the north.

In eastern Sigel Township they turn west and run along the base of the interlobate hills 1½ miles north of Verona Mills, the lower ridge being 10 or 15 feet below the upper and less than half a mile north of it. Lane[1] gives many details of this beach.

From a point a mile north of Bad Axe a low morainic ridge, separated from the interlobate hills to the south by a trough a mile wide, runs eastward for 4 miles. The beaches enter this trough at its east end but fade away toward Bad Axe.

In the western edge of Bad Axe both the Warren ridges reappear in much stronger form. The lower one is excavated a little west of the village for ballast by the railway. Both ridges are composed of rather coarser and cleaner gravel than is common.

From about 1½ miles west of Bad Axe the beach runs southwest to Popple with the highway upon its crest most of the way. In this interval it is unusually high above the plain to the northwest and from 10 to 20 feet above an extensive swamp to the east and south. In part of this stretch it is a barrier bar shutting off the low ground behind it. A mile west of Popple a high morainic knoll is heavily cut away on its northwest side at both the Wayne and Warren levels, leaving a bluff 60 or 70 feet high.

Southwestward from this point the beach runs southeast through a shallow embayment for 5 or 6 miles, and again runs southwest with reduced strength past the east side of Mud Lake. A mile southwest of Rescue it becomes a strongly wave-cut bench along the northwest face of a narrow morainic ridge (the same apparently that runs east north of Bad Axe) and so continues into Tuscola County just west of Gagetown.

Tuscola County.—From Gagetown the beach follows the inner slope of one of the later ridges of the Port Huron system southwestward to a point about 1½ miles southwest of Watrousville. In most of this interval of about 20 miles it is a strongly wave-cut shore line, with high lake cliffs at many points and with a few short intervals of a heavily formed beach ridge of gravel. West and northwest of Caro it contains large deposits of gravel. West of Watrousville it is a rather indistinct beach ridge, filling short intervals between wave-cut bluffs. But it seems probable that in the stretch from Rescue southwest nearly to Vassar much of the cutting of the moraine was done by a large river coming from the Bad Axe spillway and flowing between the ice and the moraine.

[1] Lane, A. C., Geological report on Huron County: Michigan Geol. Survey, vol. 12, pt. 2, 1900, pp. 62–73.

About 2 miles southwest of Watrousville the moraine falls 20 feet or more below the Warren beach, and two finely formed gravelly spits run off toward the southeast. About 2 miles away the beach reappears 3 miles north of Vassar on an island separated by a narrow passage from another island which extends southward with declining altitude into the village. In the western part of the village the beach is finely developed as a heavy ridge of coarse gravel and pebbles which hooks around a lagoon to the east. The water tower is on the crest of the spit.

At Vassar the Warren beach turns east across the crest of the main moraine of the Port Huron system and runs northeast along its outer face. In this stretch it is faint, for it was formed in a long narrow bay which extended northeast nearly to Cass City, tapering and shallowing northeastward.

South of Cass River the region is very sandy, and the Warren beach has not been traced continuously. The same conditions continue southwestward to Flint River.

Saginaw and Gratiot counties.—West of Flint River the horizon of the Warren beach passes out of the sand and enters a region of stony clay, a water-laid moraine. The Warren beach appears in rather light form in Maple Grove and Chesaning townships, passing about a mile south of Laytons Corners and 2 to 3 miles south of Chesaning. West of Shiawassee River the country again becomes sandy and the beach is not definitely traceable. The same conditions continue westward through Saginaw County into Gratiot County. The lowest part of the divide between the Grand River channel and the watershed of Saginaw Bay is on the county line. According to the profile of the projected Grand River and Saginaw deep waterway, the divide stands 72 feet above Lake Huron, or about 653 feet above sea level.

The whole vicinity of the divide is a region of wind-blown sand ridges and swampy lanes. The beach representing Lake Warren is a somewhat indefinite belt of sand, carrying in places low ridges of fine gravel, that runs along the southern margin of the sandy, swampy area westward through northern Chapin and southern Elba townships, with an altitude of 675 to 685 feet. The corresponding belt representing the shore on the north side was not fully traced, but it was seen 1½ miles east of Ashley. These two lines thus converge into the head of the outlet with a width of about 2 miles on the railroad line southeast of Ashley. (See fig. 1, p. 258.)

A mile southeast of Ashley the railroad crosses a rather remarkable cat-tail swamp about a mile wide and nearly 3 miles long from northeast to southwest. It appears to have resulted from the last erosion and deepening accomplished by the outlet river at the head of the Grand River channel. The swamp formerly extended down Maple River, but this connection was cut off by sediments brought by the river from the higher ground at the south and deposited on the swampy floor. The upper Warren ridge is 20 to 25 feet above the lowest part of the pass and the lower ridge is about 15 feet above it. The lowering of the lake by about 10 feet probably measures the erosion on the divide during the time of Lake Warren. The divide is on the upper edge of an eastward-sloping clay plain, but the westward gradient of the channel was then very low. (See pp. 360–361.)

Northward from the head of the outlet the plane of the Warren beach follows a broken, sandy belt into the eastern edge of Gratiot County and passes a mile or two east of Wheeler. In this interval the beach appears in some places as a low, gravelly ridge.

Isabella, Midland, and Gladwin counties.—From the Gratiot County line the beach takes a northwesterly course into the edge of Isabella County east of Mount Pleasant, and turns northeast through Midland and Gladwin counties. The predominance of sand prevents continuous tracing of the beach through this region, but fragments thought to belong to it have been seen in some places. Like the other beaches it turns south in eastern Gladwin County to get across the Port Huron morainic system and then goes northeastward through Bay, Arenac, and Iosco counties. In eastern Gladwin its plane passes through an extensive sand plain and swampy region, where it was not traced.

Bay County and northward.—The Warren beach appears in a few places in Gibson Township, Bay County, as a distinct gravel ridge. It passes northward about half a mile west of Bently and curves gradually through Adams Township, Arenac County, to the south bank of Rifle River. In this stretch it is only occasionally seen as a gravel ridge, generally appearing

as a sandy belt, considerably wind blown. North of Rifle River it runs northeast passing half a mile south of Melita to the bank of Au Gres River in Mason Township.

Farther northeast it runs near the crest of a morainic ridge half a mile west of the Cedar Valley into Burleigh Township, Iosco County. About 2 miles east of Prescott a sandy ridge, apparently corresponding in level to the Warren beach, runs south for 2 miles through southwest Richland Township, Ogemaw County.

A sandy and gravelly ridge corresponding to the Warren beach runs south a quarter of a mile east of Whittemore and west and southwest about 4 miles in moderate strength, though broken and fragmentary. Four miles northeast of Whittemore, in Reno and Grant townships, a faint sandy ridge, corresponding to the Warren beach, winds for 2 or 3 miles along the outer edge of a great sand plain which extends northeastward about 15 miles to Au Sable River and on which it finally fades away.

In the entire stretch from where it enters Bay County to the great sand plain of the Au Sable this beach appeared to mark the upper limit of submergence by lake waters. Wind-blown sand and some gravels of glaciofluvial origin lie at higher levels, but nothing indicating wave action is present.

North of Au Sable River in Iosco and Alcona counties a search was made by Mr. Leverett and the writer for the Warren and other beaches above the Algonquin, but none were found.

ONTARIO.

The shore of Lake Warren around the west, south, and east sides of the western peninsula of Ontario was traced by Spencer about 25 years ago.[1] He did not trace it continuously but identified it very accurately from place to place. He represents it, however, as extending much farther to the north on both sides of the peninsula than the facts observed justify. On the west side he found it a beach ridge only as far as Ripley, about 10 miles southeast of Kincardine, beyond which he identifies it only as a "terrace in valley." On the east side of the peninsula he found it a beach ridge as far as Brantford, describing it beyond as a "rock terrace" or "terrace."

The writer has examined this beach at several points in Ontario but has traced it continuously only in the region east of Sarnia. There and at some other points it shows the same distinctly double phase that is so well developed on the "thumb" in Michigan and in western New York. Spencer's map is on a very small scale and does not accurately represent the course of the beach, which extends considerably farther southwest east of Sarnia and southwest of St. Thomas than is shown.

ALTITUDE OF WARREN BEACH.

MICHIGAN.

In the area of horizontality the Warren beach has an altitude of 675 to 685 feet. Its crest in the Ann Arbor quadrangle is generally very close to the 680-foot contour. In the Rochester quadrangle its crest is nearer 685 feet and rises gradually northward. One and a half miles east of Troy it has an altitude of 690 feet, according to the Survey's topographic map, but this is exceptional and may be due to wind-blown sand. The northward rise probably begins in this quadrangle, for a mile south of Lenox it has become more distinctly double and the two ridges have altitudes of about 690 and 700 feet, respectively. Troy is probably slightly north of the hinge line for the Maumee beaches. The hinge for the Warren is in all probability a few miles farther north. (See fig. 7.)

At Goodells the altitude for the bay-shore ridge of the Warren is 707 feet. One-fourth mile east of Abbottsford the altitude of the same ridge is 708 feet and that of the main barrier 709 or 710 feet. On the next railroad (Port Austin branch of the Pere Marquette) the altitude of the beach 1½ miles east of Atkins is 709 feet. The altitude at this point is probably fairly accurate.

[1] Spencer, J. W., High-level shores in the region of the Great Lakes and their deformation: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 203-204.

Gordon gives the altitude a mile east of Amadore as 725 feet and at Charleston in the northern part of Sanilac County as 750 feet. Two miles farther north, at the county line, Lane makes it 750 feet. A mile east of Ruth the writer made it 748 feet, and 2 miles north of Ruth Lane makes it 756 feet. All of these altitudes in northern Sanilac County and southeastern Huron seem too low as compared with better measurements on the west side of the "thumb."

A mile and a half north of Verona Mills the altitude of the upper Warren ridge is about 775 feet. Mr. Leverett found a point a mile or so farther northwest with altitude of 780 feet. A mile and a half west of Bad Axe its altitude is about 765 feet. Lane makes it 754 feet a mile west of Popple and 744 feet at Gagetown. At the water tower in Vassar the crest of the hooked spit of the Warren beach is 709 feet. Beyond this point the first satisfactory determination of altitude was made near the head of the outlet 2 to 3 miles northwest of Chapin, where it is 675 to 680 feet. In the sandy region which stretches away to the north no good measurements are available.

In Bay County the beach has an altitude of about 761 feet near the southwest corner of Gibson Township, 764 feet west of Bentley, 770 at the north edge of Gibson Township, and

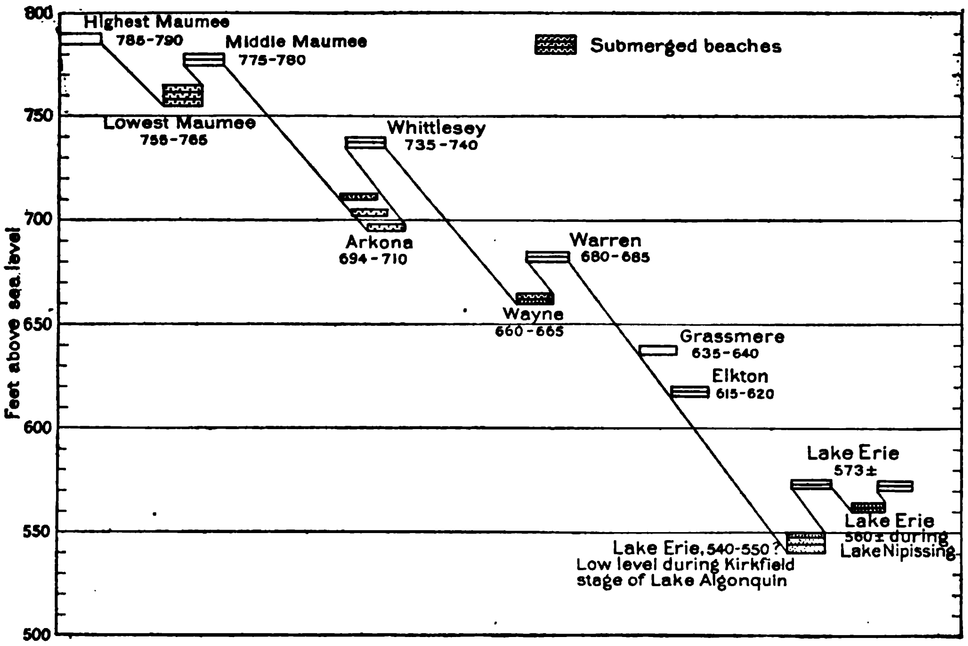


FIGURE 7.—Diagram of falling stages of lake waters at western end of Lake Erie basin.

777 feet 3 miles northwest of Sterling. These altitudes are all by aneroid and show some slight discrepancies. Farther northeast in Clayton, Mason, and Burleigh townships the altitude seems to be generally between 775 and 785 feet, reaching nearly 800 feet a mile or two southeast of Taft, near the edge of the Au Sable sand plain.

ONTARIO.

Spencer gives the following altitudes in Ontario, where he identifies this beach as a wave-made feature: Forest, 720 feet; east of Park Hill, 730 feet; near Bayfield, 767 feet; Ripley, 813 feet; Whites station (south of London) 715 feet; near Waterford, 770 feet; and at Brantford, 805 feet.

NEW YORK.

In New York the Warren beach is 858 feet above sea level at Crittenden, and it was found by Mr. Leverett to be 880 feet about a mile northeast of Indian Falls. Fairchild made many measurements of the altitude of Whittlesey, Arkona, and Warren beaches (see Pl. XVIII), but he applies a different name to the Arkona beaches in that State. Beaches corresponding to the

Arkona in Michigan he calls the "Upper Warren," and those corresponding to the Warren beaches in Michigan he calls the "Lower Warren." He gives altitudes of the "Lower Warren," at points northeast of Eden Valley only,[1] as follows: Eden Valley, 784 feet; Hamburg, 790 feet; Elma Center station, 835 feet; Steitz Corners, 835 feet; Zion Church (2 miles northwest of Marilla), 832 feet; West Alden, 830 feet; Crittenden, 858 feet; Indian Falls, 869 feet; Pond station (south of South Alabama), 887 feet. According to the writer's observations there are at West Alden five strands which are lower and appear to be distinct and separate from the higher Arkona group that runs on to Alden. The road corner at West Alden is on one of these at 845 feet. Another, apparently the highest of the lower group, is less than a quarter of a mile southeast of the corner and is 3 or 4 feet higher. Four of these ridges are related to a delta and fade out in less than a mile northeast of the corner at the south side of Ellicott Creek, only the lowest crossing this creek. These bars do not terminate like the ridges that run through Alden; they stop at the edge of the delta apparently on account of lack of beach-making material and not because they are buried under gravel. The altitude of the beach at Crittenden is 858 feet 4¼ miles northeast of West Alden. The highest rate of rise that Fairchild gives is 2.6 feet to the mile from Crittenden to Pond Survey station. The beach at the corner at West Alden is 845 feet or 13 feet below the Crittenden ridge. At Fairchild's highest rate of rise the difference should be only 11 feet, but this interval is south from Crittenden and the rate should be a little less, and it seems likely that the first bar east of West Alden is the real correlative of the Crittenden ridge. It seems to the writer that Fairchild's measurement at Zion Church is also too low and probably falls below the upper strand of the lower group.

In determining the rate of rise in western New York Fairchild uses "the Whittlesey and the stronger Upper Warren (Arkona) bars." He seems to use the latter beach to measure the uplift to Crittenden and to Pond Survey station, although these places are both beyond Alden, where his Upper Warren (Arkona) group ends.[2] He finds the whole uplift from the State line northeast to Pond station to be 149 feet in 92.5 miles, or at the rate of 1.61 feet per mile. Near the State line the uplift is about 1 foot per mile, and from Crittenden to Pond station it is 2.6 feet per mile. From the Cattaraugus Valley north the average is somewhat more than 2 feet per mile. (See Pl. XVIII.)

GLACIAL BARRIERS OF LAKE WARREN.

In the Niagara region in New York and on the Niagara peninsula in Ontario the Niagara Falls moraine appears to mark the place of the eastern barrier of Lake Warren. If it is found possible to recognize and trace water-laid moraines in the somewhat hilly country of western New York the place of the barrier east of the Niagara quadrangle may be definitely determined.

In Michigan the meeting place of the Warren beach and the ice barrier was somewhere near Au Sable River west of Harrisville or southwest of Alpena, but on account of the great quantity of sand there seems little hope of tracing it in that region. It may be marked by either the Bay City or Tawas moraine. (See fig. 6, p. 370.)

In Canada two localities seem favorable for the determination of the barriers. One is on the slope toward Lake Ontario west or northwest from Toronto; the other is on the east side of Lake Huron north of Wingham, but neither of these localities has been studied.

CORRELATIVES OF LAKE WARREN.

In the west the principal correlatives of Lake Warren were Lakes Chicago and Duluth, both lakes attaining their maximum extent about at the same time. In the east, so far as known, the correlatives of Lake Warren within the drainage basin of the Great Lakes were confined to some small lakes in the Finger Lake region in New York and glacial lakes in the southern part of the Georgian Bay basin and the basin of Lake Simcoe, including perhaps some part of the Trent Valley region. These lakes as well as those in New York discharged westward to Lake Warren.

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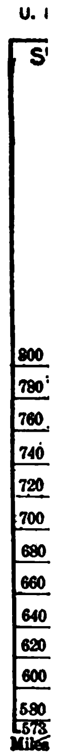
[1] Fairchild, H. L., Glacial waters in the Lake Erie basin: Bull. New York State Mus. No. 106, 1907, p. 65.
[2] Idem, p. 77.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800
780
760
740
720
700
680
660
640
620
600
580
573
Miles

CHAPTER XX.

GLACIAL LAKE LUNDY (LAKE DANA, LAKE ELKTON) AND THE TRANSITION TO LAKE ALGONQUIN.

By Frank B. Taylor.

HISTORY.

When the waters fell from Lake Warren they rested first at the Grassmere beach and later at the Lundy (Dana, Elkton), which is a weaker strand at a slightly lower level. Both of these beaches are horizontal to a point a few miles north of Black River in northeastern St. Clair County, but north of that they rise gradually at least as far as the outer part of the "thumb," where they turn westward into the basin of Saginaw Bay. The Grassmere splits northward with increasing vertical intervals between the separate strands and the Lundy splits in less degree. These splittings show that sharp differential elevation of the northern part of the "thumb" took place during the building of these beaches.

During the time of the Grassmere beach the waters of the Lake Huron and Lake Erie basins were connected by a shallow strait, which varied greatly in width and at one or two constricted points was so narrow and shallow that it may have had a slowly flowing current, though not one sufficient to constitute it a river in the ordinary sense. (See Pl. XIX.)

When the waters fell to the level of the Lundy beach they flowed for a brief time with a strong current (as shown on fig. 10) over the top of the main moraine of the Port Huron system at St. Clair, 11 miles south of Port Huron. (See pp. 474–475.) As the moraine was composed of unconsolidated drift materials, it was soon cut through and Lake Lundy came to one level on both sides with its outlet near Syracuse, N. Y., and is therefore not to be regarded as an early stage of Lake Algonquin. Later, when Lake Lundy began to fall, two other barriers made their appearance, one at Detroit (the Detroit interlobate moraine) and the other near Trenton and Amherstburg. The latter was composed largely of ordinary till or bowlder clay, but partly of closely packed bowlders and partly of bedrock. The present channels through this ridge are in till, but the main channel, which passed originally close along the east side of Grosse Isle, resting on bedrock around Stony Island, has now shifted farther east, where the rock surface is lower and the bottom is hard, very bowldery till.

The uncovering of these barriers brought St. Clair and Detroit rivers and Lake St. Clair into existence and inaugurated Lake Algonquin, the largest of the glacial lakes in the Great Lakes region.

The studies in the Niagara region have shown that Fairchild's Dana beach and Spencer's Lundy beach are the same. As the name Lundy was applied at an earlier date it is adopted here.

OUTLET.

The outlet of Lake Lundy has not yet been determined by continuous tracing of the beaches into close connection with it, but Fairchild [1] has shown that during the time of the Lundy or Dana beach it was in all probability through the great Marcellus-Cedarvale channel which crosses the front of the hills southwest of Syracuse, N. Y. It is certain that the outlet was not by the Grand River channel to Lake Chicago, for the divide at the head of that channel has an altitude of 653 feet and was within the area of horizontality, in which the Grassmere beach has an altitude of 640 to 645 feet and the Lundy beach is about 20 feet lower. It seems clear also that the outlet was not northwestward to Lake Chicago along the hills northwest of

[1] Fairchild, H. L., Glacial waters in the Lake Erie basin: Bull. New York State Mus. No. 106, 1907, p. 44; Glacial waters in central New York: Bull. New York State Mus. No. 127, 1909, p. 53 and Pl. XL.

Alpena, for when the lake fell to a level 20 feet lower than the Grassmere beach, the discharge from the Lake Huron basin was southward to the Lake Erie basin. The marks of that discharge are very plain. If the outlet of Lake Lundy had been northwestward to Lake Chicago at the time of the Grassmere beach the waters would hardly have flowed south when the ice front drew back far enough to let the lake level fall 20 feet lower.

GRASSMERE AND LUNDY BEACHES.

DISTRIBUTION.

MICHIGAN.

Monroe and Wayne counties.—In Monroe County the Grassmere beach is not so strongly developed nor so well defined as the Wayne beach. It often seems like a lower level of that beach, especially where they stand close together. It starts at the State line about a mile east of the Wayne beach which it closely parallels to Raisin River. Its altitude is about 640 to 645 feet.

A separate, narrower sandy belt which runs northeast from the State line, passing a mile or two east of Temperance and Yargerville, about 4 miles west of Monroe, 2 to 3 miles west of Steiner and Grafton, and through Carleton, is designated by Sherzer the Grassmere beach; but its altitude is 615 to 620 feet, and it corresponds, therefore, quite clearly to the Lundy beach farther north.

The sandy belt representing this beach is considerably more scattered and patchy than the sandy parts of the Grassmere, and it is not so strongly developed. As mapped by Sherzer it enters the Romulus quadrangle in the northwest corner of Frenchtown Township as a sandy belt about 2 miles wide.

In this flat region only its general course can be indicated. In general, its axis lies 1 to 1½ miles east of the 620-foot contour, passing out of the quadrangle about a mile east of Taylor. For about 2 miles farther it runs northeast through the northwest corner of the Wyandotte quadrangle and then northwest through the southwest corner of the Detroit quadrangle. It here swings west about a mile into the Wayne quadrangle and passes a little west of Dearborn.

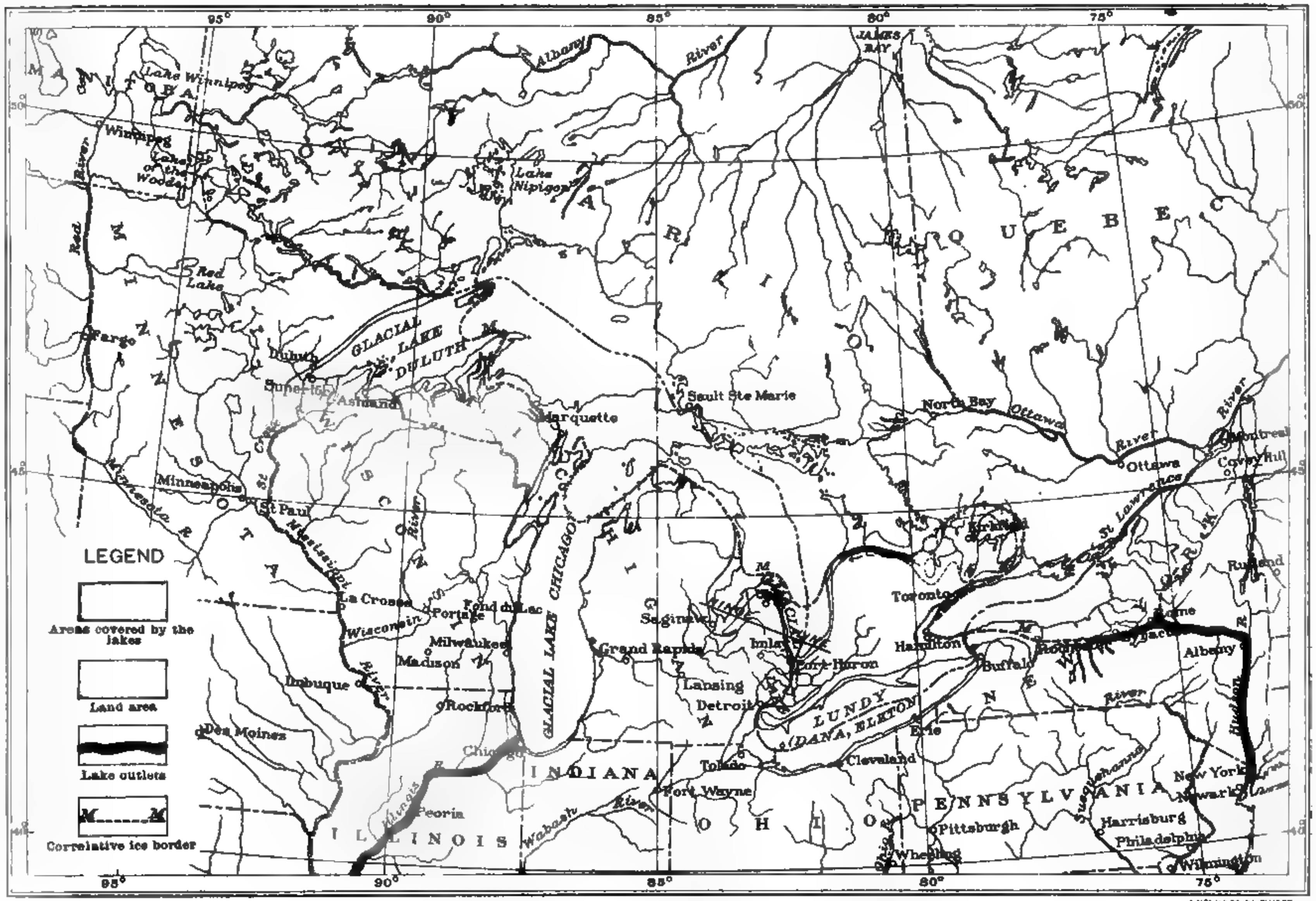
In the Romulus quadrangle the Grassmere beach is very sandy and poorly defined. From 1½ miles west of Maybee its course is about north to Stony Creek, where it turns northeast to New Boston.

In the Wayne quadrangle the Grassmere beach is more diffuse and sandy. It passes through Eloise (2½ miles east of Wayne) and a mile east of Livonia, and thence, keeping about a mile south of the Wayne beach, into the Detroit quadrangle. For 2 or 3 miles south of Eloise it is fairly well developed, but is generally merely an irregular and ill defined sandy belt.

The Grassmere beach rounds the Detroit interlobate moraine in a much wider curve than the Wayne. It passes eastward about a mile north of Howlett and turns north through Palmer Park, the main ridge passing about 1½ miles west of Highland Park. The sandy deposits at Highland Park and for a mile or two southwest of there belong to this beach. From Palmer Park the Grassmere passes a mile east of Royal Oak. From where it turns north the beach is composed of fine sand, much wind blown, and is very irregular and ill defined.

Entering the Detroit quadrangle at Dearborn, the Lundy beach runs eastward through the central part of Detroit. For some distance in the western part of the city it lies not far south of Grand River Avenue, but continuing eastward it crosses to the north side and passes about half a mile north of Grand Circus Park. In the eastern part of the city it lies mainly about a mile back from the river and swings northward through Elmwood and Mount Elliott cemeteries, running thence half a mile to a mile east of Gratiot Avenue. It keeps the same course through the Grosse Pointe quadrangle but after crossing the county line lies nearer Gratiot Avenue.

Through the city this beach is simply a belt of low, scattered sandy knolls and fragmentary ridges, few of which remain in the business section, though many persist in the residence parts of the city and in the suburbs and in Elmwood and Mount Elliott cemeteries.



MAP OF GLACIAL LAKES DULUTH, CHICAGO, AND LUNDY (DANA, ELKTON)

100 0 100 200 300 Miles

1914

A. HOEN & CO. BALTIMORE

By Frank B. Taylor

Macomb County.—From Royal Oak the Grassmere beach keeps closely parallel with the Wayne to a point 2 miles northeast of Big Beaver, whence it runs directly northeast to Utica. It is sandy and weak but is stronger and somewhat gravelly at Utica, where it runs through the south end of the village half a mile south of the Wayne beach. Northeast of Utica it passes into an extensive sandy area, largely of dunes, through which it is not definitely traceable. It probably follows the heavier line of the deposit about northeast for 4 or 5 miles. In Macomb Township it appears to be lost in a wide sandy area. Possibly it runs into the south edge of Ray Township, but it was not certainly identified for 6 or 7 miles toward the east.

At New Haven it follows the crest of the Mount Clemens moraine as a sandy beach ridge, which is well developed at the west edge of the village. It runs about 2 miles northeast and 4 miles southwest from this place. Three miles east of New Haven it appears as a north-south gravel ridge about 2 miles long, and a mile farther south as a fragment on the back of the Emmett moraine. As a rather light but finely formed gravel ridge, it runs 2 miles east from the center of sec. 30, Casco Township, and passes a little south of the corner at Casco, curving around to the Belle River at Adair, where it expands to more than a mile in width.

From the Grosse Pointe quadrangle the Lundy beach continues toward Mount Clemens, and for several miles north and south of this place it rests on or very near to the crest of the Mount Clemens moraine as a rather faint fragmentary gravel ridge. Several such gravel deposits occur at and north of the railroad station in Mount Clemens.

The Mount Clemens moraine forms the eastern barrier of a wide, flat valley, which is drained by the several branches of Clinton River, and which, at the time of the Lundy beach, was a bay of considerable extent with a narrow shallow outlet eastward at Mount Clemens. The southwestern part of this bay lies in the Rochester quadrangle. No definite beach was found at the Lundy level, but the southern part of the area, south and east from Warren, is sandy and often suggests a beach. On the clay plain north of Warren no certain evidence of the beach was found.

Some small gravelly ridges of the Lundy run from Mount Clemens northward past Chesterfield and, passing a mile or two south and east of New Haven, turn eastward across the wide clay flats north of Lake St. Clair. The beach is not traceable continuously through this region. Some light gravel ridges belonging to it lie on the Emmett moraine for a mile or two northwest of New Baltimore.

St. Clair County.—East of New Baltimore the Lundy beach appears to run as a faint gravelly belt across the south edge of Casco Township to the southwest corner of China Township. From here it runs as a distinct sand belt northeast to Belle River and thence north to Pine River west of St. Clair.

From the sandy delta at Adair the Grassmere beach runs north, passing a mile west of Smith Creek and just east of Burns to Pine River. Three miles north of Adair it becomes very sandy for 2 miles and widens to nearly a mile. Thence nearly to Burns it is gravelly, but from Burns to Pine River it is again fine sand.

Half a mile east of Kimball two slender gravel ridges appear on the east side of Pine River and run south about 2 miles before being lost in dunes. The higher dune ridge west and southwest of Port Huron appears to belong mainly to the Wayne beach and the lower one to the Grassmere beach.

About 3 miles west of St. Clair River at Port Huron a belt of dunes runs south to the bank of the river 5 miles north of St. Clair. This dune ridge does not much resemble a shore line, but it seems to be about at the level of the Lundy beach. The level of the beach runs north across the upper edge of the great sandy delta of Black River northwest of Port Huron.

Sanilac County.—North of Black River both the Grassmere and Lundy beaches are very faint gravelly belts, but about 5 miles from the river both of them become fairly strong, continuous ridges, generally gravelly, running northward through Sanilac County. The beaches are sandy in some small localities farther north on the "thumb," but little of the sand is wind

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blown. Up to the south line of Huron County the beaches of this district were studied in considerable detail.

To a point within about 8 miles of the north line of Sanilac County the Lundy beach runs parallel with the Grassmere and generally a mile or less from it. Both are distinct individuals throughout and may easily be traced continuously.

Westward from a point west of Port Sanilac the Grassmere beach is perceptibly wider than for some miles south of that place. About 2 miles southwest of Richmondville it divides into two distinct ridges, which separate rapidly, and at a distance of 6 miles are fully a mile apart. Farther north they draw in again to about half a mile. The lower and easternmost ridge appears to be the stronger, continuing north for 5 or 6 miles with about the same strength as the undivided beach. About 2 miles west of Forestville the upper ridge splits into two slender strands which are nearly a quarter of a mile apart at the county line.

Five miles south of the north county line the lower or main ridge divides again into two ridges which at the county line are a mile apart.

Three miles south of the county line the lower ridge splits once more into two strands which are about half a mile apart at that point. The upper ridge of this pair is considerably the stronger, the lower being weak and fragmentary. The weakness of this lower strand would lead one to expect that any further splitting would appear in some of the higher, stronger strands.

A distinct gap between the lowest of the Grassmere strands and the Lundy beach, with apparently no tendency to beach formation, is taken to represent a lowering of the outlet and to correspond to the interval between the two beaches farther south where they are both single.

About 3 miles north of Lexington the Lundy beach becomes wider than for some miles to the south. In secs. 35 and 26, Sanilac Township (T. 11 N., R. 16 E.), the beach is very wide, and for 2 miles is partly cut away along the shore in a fresh lake cliff. It happens that just about at this place the Lundy beach begins to rise above its level in the area of horizontality. It seems probable that the beach splits at this point, but to determine this fact accurately leveling is needed. Nearly all the measurements made by the writer in this region were by aneroid barometer, with a few by hand level. Between Port Sanilac and Richmondville a fragment of beach, which has recently been extensively cut away both to the north and to the south, lies half a mile to a mile east of the main line of the Lundy, which runs north from Black River. The aneroid measurements of altitude indicate that this is a part of the Algonquin beach, but it is barely possible that the measurements are inaccurate and that this is in fact a lower, undisturbed strand of the Lundy. This is suggested further by the fact that a beach fragment about a mile long on the bluff 4 miles north of Richmondville and another 1 to 3 miles north of Forestville appear to have the altitude of the Lundy in the area of horizontality.

From the bluff 6 miles north of Lexington the main ridge of the Lundy runs north as a distinct and rather wide beach to about 3 miles north of Richmondville, where it splits into two distinct, lighter ridges. These run about 5 miles north to the county line and are generally a quarter of a mile or less apart. Thus, at the north line of Sanilac County, the Grassmere beach is represented by five beach strands in place of one south of Richmondville, and the Lundy is represented by two and possibly three strands in place of one south of Lexington.

Huron County.—Lane recognized the increase in the number of beaches in Huron County, but he did not trace any of them continuously. The writer's studies in this county have been confined mainly to the Port Huron morainic system and associated drainage channels, to the Warren beach, and to the Algonquin and Nipissing beaches close along the present shore, and these studies were made mainly in 1896, only four days having been spent in the county since that time, mainly on the lower beaches.

A series of beaches lies above the Algonquin in Gore, Huron, Bloomfield, and northwestern Sigel townships. Nearly all are faint. One rather stronger than the rest was followed continuously for a number of miles in Huron and Bloomfield townships. Below this in Huron and Gore townships there are 8 or 10 light gravelly ridges above the Algonquin.

The beaches in these townships have not been traced to continuous connection with the identified beaches either to the south or west, so, although it seems certain that the upper members of the series belong to the Grassmere and the lower ones to the Lundy, there is no means at present of distinguishing between the two groups. A number of light beach ridges and several low lake cliffs with stony or bowldery flats in front of them were seen along the railroad between Bad Axe and Port Austin.

Between Bad Axe and Elkton the writer found a series of beaches closely resembling those at the north line of Sanilac County. Most of those seen, however, belong to the Grassmere, for several members of the Lundy (Elkton) are farther west between Elkton and Bayport.

Southwestward from Grassmere the writer followed two of the stronger Grassmere beaches through Canboro into Tuscola County, 2 or 3 miles west of Gagetown. Two or three of the upper members of the Lundy group were also seen at intervals southwest of Elkton, passing Wolfton and Creel City.

Tuscola County.—In Tuscola County the principal ridges of the Grassmere and Lundy beaches were followed from Elmwood and Columbia townships southwestward about to the highway which connects Vassar and Richville. Between Fairgrove, Watrousville, and Vassar on the east, and Reese and Richville on the west, the beaches were studied in some detail. The tendency to double ridges, which is so clearly shown by all the beaches on the road between Reese and Watrousville, may be due in part to splitting, but the area covered in detail was not large enough to determine the relations conclusively. The courses of the several beach ridges in Tuscola County are shown in part but not fully on Davis's map of the surface geology of the county.[1]

Saginaw Bay district.—South of Cass River the Grassmere and Lundy beaches pass out upon the sandy floor of the Saginaw Valley and presumably lie on the gentle slope in their usual relation to the higher beaches. Fragmentary gravelly ridges are well defined in certain places, as in Maple Grove and Chesaning townships in southern Saginaw County, and probably belong to the Grassmere and Lundy beaches.

In Midland County there are some fragmentary ridges, but they are nearly all composed of fine sand and their present forms are wind made, not wave made. The altitudes indicate that the Grassmere beach enters the southern edge of Gladwin County barely if at all, and that the Lundy does not enter it. Both turn back toward the southeast through eastern Midland County to get across the Port Huron morainic system. Thence they run northward through northwestern Bay County and through central and eastern Arenac County to the vicinity of Au Sable River in eastern Iosco County.

Through the entire sweep of the Saginaw Valley from Cass River to Tittabawassee River in northern Midland County and thence to northern Bay County the levels of the Grassmere and Lundy beaches lie on a flat clay plain, considerable areas of which are covered with fine wind-blown sand. The beaches appear to have been composed of sand and have been so extensively modified by wind action that almost no true beach forms remain. Where the sand does not form dunes it is generally without definite expression.

Neither the Grassmere nor the Lundy has been surely identified in this sandy region. Certain wind-blown sandy ridges appear to correspond to them in a general way, but they are not true beaches in their present forms. In Saginaw, Midland, Bay, and Arenac counties some of the wind-blown ridges bear a slight resemblance to true beach ridges and have been so described and mapped by W. F. Cooper,[2] but are shown by their details to have been shaped by the winds. Their steeper slopes generally face eastward, less often northward or southward, but so far as known never westward. The best types have almost invariably hummocky

[1] Davis, C. A., Geology of Tuscola County, Mich.: Ann. Rept. Michigan Geol. Survey, 1908. The old beaches are discussed in brief general terms only. The map is mainly a soil map and shows the beaches by two different symbols, which cover also other forms of surface deposit which produce similar soils. The Algonquin and Nipissing beaches near the present shore of Saginaw Bay are well represented, but the mapping of the older, fainter beaches at the higher levels is incomplete.

[2] Cooper describes these forms in considerable detail in his report on Bay County: Ann. Rept. Michigan Geol. Survey for 1905, pp. 343–348; map opposite p. 337. Also, Pleistocene beaches of Saginaw County: Tenth Ann. Rept. Mich. Acad. Sci., 1908, pp. 90–98. Most of the lower ridges here considered are of the same wind-blown sand type. Only a few are of gravel, but their composition is not stated.

westward slopes rising gently eastward and descending steeply to the clay plain on the east. Although the country is flat, these sand ridges show no rectilinear forms, such as waves are wont to make under such simple conditions and such as are seen in the Algonquin and Nipissing beaches in these same counties. Instead, the eastward fronts of these forms follow extremely sinuous lines with sharp salients and deep reentrants, making the sinuosities of the front relatively minute. Still more decisive as to their real character are the facts that they run up or down the slope at all levels and that they have no visible surf-wasted or wave-worn belts in front of them. Even in default of other features suggesting shore lines at the levels of the Grassmere and Lundy beaches, these wind-blown deposits can not be regarded as representing those beaches in their original places and relations.

Arenac and Iosco counties.—The obscuration of the beaches by sand in Arenac and Iosco counties is almost as complete as it is in Saginaw, Bay, and Midland counties. In northern Bay County a gravelly beach ridge in fairly good development appears now and then between the sandy areas. Small fragments of gravelly beaches in Bay, Arenac, and Iosco counties below the Warren and above the Algonquin have been found by Leverett, Cooper, Gregory, and the writer, but none of them have been traced continuously and their identity remains somewhat doubtful. Around Standish fragments were found that probably belong to these beaches, and west and northwest of Tawas apparently corresponding light, fragmentary, gravelly beaches were found, which, with some breaks, extend northward from Tawas nearly to Au Sable River.

Alcona County.—In Alcona County north of Au Sable River a careful search was made by Mr. Leverett and the writer for beaches above the Algonquin, including the Lundy, Grassmere, Wayne, and Warren, but no certain evidence of any such was found.

OHIO, PENNSYLVANIA, AND NEW YORK.

The Grassmere and Lundy beaches have not as yet received particular attention in Ohio and Pennsylvania. Sandy and gravelly belts, generally ill defined, were found near Toledo, Sandusky, and Huron, Ohio, which in all probability belong to these beaches. The same forms were seen occasionally as far east as the Cattaraugus Valley in New York. From this valley northward to the Niagara quadrangle only a few faint and unconnected fragments of shore lines have been observed in the interval usually occupied by these beaches. A faint beach near Elma, 17 miles southeast of Buffalo, appears to correspond in its general relations to the Grassmere beach in Michigan. Its altitude at Elma is 767 feet above sea level, or about 75 feet below the Warren beach 2 miles southeast, and fragments of it were found at several places northeast and southwest of this place. Several other faint fragments at lower levels were found by Mr. Leverett in the same neighborhood and probably belong either to lower strands of the Grassmere or to the Lundy beach. In the Niagara quadrangle the Lundy or Dana beach is represented by a number of unconnected fragments near Akron, near Pekin, and at Niagara Falls, Ontario, and is probably represented by fainter lines at several lower levels.

ONTARIO.

In Ontario, between Sarnia and Wyoming, faint gravel belts were found for both of these beaches, but they were not traced any distance. On the slope between Forest and Lake Huron no certain evidence of the Grassmere beach was found and the Lundy beach has probably been cut away by the modern lake. Faint gravel ridges marking the Grassmere and fairly strong ones belonging to the Lundy were found north of Thetford. Near Essex, Leamington, Blenheim, and Ridgetown both of these beaches were found, generally in faint form, but the Grassmere near Essex and Leamington is rather strong. Near Port Rowan and Simcoe both beaches are marked by belts of sand. The Lundy beach was traced 50 miles westward from Buffalo and found to be nearly horizontal, leaving no serious doubt that it is the same beach as Lane's Elkton beach, which has been traced some distance eastward in Ohio and Ontario.

The various levels at which the fragments are found around Buffalo strongly suggest a northward splitting like that found on the "thumb" in Michigan. The area, however, has not yet been studied in sufficient detail to warrant a positive statement on this point.

ALTITUDE AND NORTHWARD SPLITTING.

In the area of horizontality the Grassmere beach has an altitude of 640 to 645 feet and the Lundy of 615 to 620 feet. Both beaches appear to keep their horizontality farther north than the beaches above them, for they appear to begin to rise about at Lexington in Sanilac County or perhaps 2 or 3 miles north of this place. For 20 miles north of Lexington the rise of both beaches is gradual, averaging for the upper Grassmere strand scarcely a foot to the mile. West of Richmondville, where the Grassmere beach begins to split, its upper strands rise more rapidly, but the Lundy continues at about the same rate. The measurements of altitude on the Warren beach from Bad Axe southwest into Tuscola County were made chiefly by Lane. If the isobases be laid out with reference to these measurements and projected southeastward in courses parallel with those farther south they do not accord with the measurements now available in Sanilac County. If the measurements are correct there is a marked local relative depression in southeastern Huron and northern Sanilac counties—a thing that seems quite improbable.

The beach series a mile south of the north line of Sanilac County is rather remarkable. Mr. Leverett made wye-level measurements in 1912 which show the following series:

Section of beach series in north Sanilac County, Mich.

1. A freshly cut bluff of clay and sand 46 feet high. The Nipissing and Algonquin beaches have both been cut away at this locality.
2. A sandy ridge at 626 feet and gravelly ridges at 652 and 656 feet. These three appear to belong to the Lundy.
3. A light, broken ridge at 673 feet; a bowldery strip at 680 to 683 feet; and sandy beach ridges at 688, 699, and 703 feet. These ridges appear to belong to the Grassmere. The bowldery belt may be a washed-down fragment of the Bay City moraine, or it may be merely the surf-wasted zone belonging to the beaches next above it.
4. Four faint washed-down ridges at 717.4, 721, 722, and 727.5 feet. These appear to belong to the Wayne.
5. Two closely set, weak sandy ridges at 735 and 738 feet and at the top of the series the strong, highest beach ridge of this region at 752 feet. These three appear to belong to the Warren. Mr. Leverett ran a wye-level line along the upper Warren ridge about N. 35° W. from this east-west line to Ruth, 4 miles distant, and found a rise of 4.5 feet, or to 756.5 feet.

From these measurements it appears that the interval between the highest and lowest Warren is 15 to 20 feet; from the lowest Warren to the highest Wayne, 8 to 10 feet; from the highest to the lowest Wayne, about 10 feet; from the lowest Wayne to the highest Grassmere, 14 to 15 feet; from the highest to the lowest Grassmere, about 30 feet; from the lowest Grassmere to the highest Lundy, about 17 feet; from the highest to the lowest Lundy, 30 feet, and from the lowest Lundy to the Algonquin, supposing 605 to 607 feet to be the altitude of the latter, 20 to 25 feet. (See Pl. XX.)

On a line running west from Bad Axe there is a similar series of beach formations, but their number and altitudes have not been accurately determined, and no continuous tracing has been done on the beaches between the Warren and the Algonquin, excepting southwestward on two strands of the Grassmere, as noted above. Nevertheless, Lane,[1] in his report on Huron County, although he had not traced any of the beaches continuously, assumes substantial horizontality for the Grassmere beach around the "thumb," and the same interpretation must necessarily be extended to the Lundy. But in reality the attitude of the beaches can not be settled until the individual strands have been traced and accurate measurements of their altitudes made. At present, with the Warren beach rising from 709 feet at Vassar on the west side to 775 or 780 feet northeast of Bad Axe, with the Wayne beach keeping closely parallel in altitude, with the upper strands of the Grassmere rising 50 or 55 feet (640 or 645 to 695 feet) from the area of horizontality to the north line of Sanilac County, and with the Lundy rising 35 or 40 feet (615 or 620 to 655 feet) in the same interval, Lane's view that the Grassmere beach

[1] Lane, A. C., Geological report on Huron County: Michigan Geol. Survey, vol. 7, pt. 2, 1900; chap. 4 and particularly pp. 73-74.

"seems to be quite horizontal in its course around the 'thumb'" seems incorrect. The facts now in hand show that the Warren beach rises about 100 feet from the area of horizontality to its highest point northeast of Bad Axe, and also that the uplift which tilted and split the Grassmere and Lundy beaches amounted altogether to nearly 100 feet at the north line of Sanilac County.

The relations in Sanilac County show clearly that the uplift which raised and tilted the Wayne and Warren beaches occurred after the formation of both these beaches and before the formation of the Algonquin beach. The Grassmere and Lundy beaches fill the interval both in time and space and their tilting and northward splitting is in close accord both in amount and distribution with the uplift of the Warren beach.

In view of these facts it seems certain that these beaches descend southwestward along with the Warren beach on the west side of the "thumb," just as they ascended northward with it on the east side.

Lane suggests that the Grassmere beach passes above the head of the Grand River outlet channel, affording an outlet for Lake Lundy in that direction. But if the writer's results are correct, the head of that outlet is within the limits of the area of horizontality and the Grassmere beach falls a trifle below it; and further, if the writer's tracing and measurements of altitude are correct, the upper strand of the Grassmere descends from about 720 feet altitude about a mile east of Grassmere village to about 680 feet about 4 miles east of Reese in Tuscola County.

So far as known to the writer, there is no locality in the Great Lakes region so favorable as this for the study of the effects of progressing differential uplift on beaches then being formed. But such a study, to attain the best results, requires careful tracing of the individual beaches and accurate measurements of their altitudes at short intervals of distance. The area in which such work should be done comprises Sanilac, Huron, and Tuscola counties. Such a study on the Grassmere and Lundy beaches in these counties gives promise also of very valuable results bearing on the time factors involved and hence on the determination of the rate of deformation or uplift, for this uplift of 100 feet or more occurred while these two beaches were being formed, and is definitely limited in time to the interval between the close of Lake Warren and the beginning of Lake Algonquin.

In discussing the sand ridges and beaches of Bay and Saginaw counties, referred to above, Cooper generally assumes horizontality, although continuous tracing was not done. The southern part of the area which he discusses lies in the region of horizontality for all the beaches, and more of it for the lower beaches. But the higher beaches of Bay and Gladwin counties can hardly be horizontal, when the upper Arkona rises from about 710 feet 2 miles northeast of Elsie to 815 feet 6 miles northeast of Gladwin.

GLACIAL BARRIERS OF LAKE LUNDY.

The precise location of the ice barriers of Lake Lundy is not known. It seems necessary to infer the presence of an ice barrier on the middle slope of the highlands west of Alpena, for if there was an outlet northwestward for the Grassmere stage of Lake Lundy along that slope it would have continued to carry off the discharge during the time of the Lundy beach, which is about 20 feet lower, but this it did not do. (See also pp. 399–400.)

On the other hand, any ice barrier near Syracuse, N. Y., must also have rested at a certain definite place on the face of the northward-sloping escarpment. As already stated (p. 399), Fairchild identifies the Marcellus channel southwest of Syracuse as the outlet of Lake Lundy (Dana), but the correlative position of its front has not yet been determined. In the Niagara region the indications are that the barrier of Lake Lundy stood somewhere between the Niagara escarpment and the present shore of Lake Ontario. Thus, while the precise positions of the barriers are not known in Michigan or New York, they must have been within very narrow zones in each locality.[1]

[1] See fig. 6, p. 370; also, Niagara folio (No. 190), Geol. Atlas U. S., U. S. Geol. Survey, 1913, p. 18.

TRANSITION TO LAKE ALGONQUIN.

When the waters fell to the level of the Lundy beach they were barred by the Port Huron moraine (here a single, simple, smooth ridge), a mile north of the village of St. Clair (as shown on fig. 10), until they could cut a short, shallow channel through it. (See p. 474.) This was done quickly, for the beach was made south of the barrier as well as north of it. Hence, after cutting through the moraine the lake waters soon came to one level on both sides of it and stood in that position while the Lundy beach was being made.

This stage of the waters might be regarded as the beginning of Lake Algonquin, but such was clearly not its real relation. The lake at the time of the Lundy beach was simply a lower stage of Lake Lundy. The uncovering of a barrier between Lake Huron and Lake Erie, through which the waters found it necessary to cut a channel, makes this stage technically transitional between Lake Lundy and Lake Algonquin. While the first or higher channels were being cut through the barrier the waters in the Lake Erie basin stood a few feet lower, and although this condition lasted only a very short time, it separated the Huron-Erie waters into two bodies with their surfaces at different levels. The moraine, however, was not able to hold the waters against the eroding power of the river long enough to make shore lines at different levels on the two sides, so that the Lundy beach marks the lake surface as the waters stood after the first channels had been cut and the waters had come practically to one level.

After standing for a time at the Lundy beach the waters fell to a lower level, probably on account of the withdrawal of the ice from the escarpment south of Syracuse and the opening of a lower outlet. This renewed the channel cutting through the Port Huron moraine at St. Clair and soon inaugurated the cutting of a similar channel through the interlobate moraine at Detroit and through another barrier at Trenton. (See pp. 476, 485–492.) All of this channel making from the first cutting through the Port Huron moraine was done by a river flowing from north to south—that is, from the basin of Lake Huron to the basin of Lake Erie—and the fall of the waters from the Lundy beach resulted in the final separation of the lakes in the Erie-Ontario basin from those in the Huron basin. The cutting on the Trenton barrier soon passed the rapid stage and became very slow. The barriers at St. Clair and Detroit were soon cut down to a low grade with reference to the Trenton barrier, and then a relatively stable state for the connecting rivers and for the lake above was established. This was the beginning of Early Lake Algonquin.

There are one or two other remote alternatives as to the precise order of events at the beginning of Lake Algonquin. An outlet to Lake Chicago or to Lake Simcoe and the Trent Valley may possibly have occurred before the morainic barrier at St. Clair was uncovered, so that when the waters fell to the level of the barrier's crest, there was no tendency to overflow toward the south or to make a channel through it in that direction. But even then, unless there were at the same time an eastward outlet for the waters in the Erie-Ontario basin, the discharge of those waters would have had to pass northward across the barrier and would have cut channels in that direction. But the first flow over the moraine left a clear record in distributary channels which prove absolutely that the flow was southward.

If, perchance, outlets were opened both to Lake Chicago and near Syracuse at the same time, so that the moraine at St. Clair might be uncovered without making a channel across it in either direction, this barrier might have been left unbroken. Then later, when the waters on the two sides came to have different levels, it is perhaps conceivable that the barrier held the waters in one of the basins at a higher level than they would have maintained had the barrier been broken. Indeed, it is necessary to believe this if Spencer's opinion that Lake Algonquin had no southward outlet be accepted. But against this view, the distributaries (see fig. 10) show plainly that the first flow over the moraine was southward at a level a few feet higher than the Lundy beach and also that the channel was not made by a small stream but by a river of great volume. These facts seem to make the last two alternatives untenable. Indeed, if the last alternative is accepted St. Clair and Detroit rivers could have come into existence only by a

cutting of the barrier at St. Clair by some small stream, the small opening thus made being later appropriated and enlarged by the great river. If the great river did not break through the barrier at the first fall of the waters to Lake Lundy and succeeding early stages of Lake Algonquin, it could not have broken through later by its own action at all, because in the later lake stages the ice did not again close the northwestward connection with Lake Chicago. The lake level at Port Huron did not again rise above 607 feet, because the overflow passed out partly by way of Chicago and prevented any further rise of the water level at Port Huron. The distributaries at St. Clair show plainly that in order to overtop the barrier the waters at Port Huron would have had to rise to 630 or 635 feet altitude. But this would have been impossible with the Chicago outlet open and freely connected with the waters in the Huron basin.

Hence, although from present knowledge of the moraines it seems hard to believe that at so late a stage of the ice retreat the ice was still barring the passage to Lake Chicago west of Alpena and to the Lake Simcoe basin east of Owen Sound, yet the character and relations of the distributaries at St. Clair seem to leave no other alternative. It is therefore concluded, provisionally, that Lake Algonquin developed directly from the Lundy stage of Lake Lundy and had an early stage during which its whole discharge passed southward to the Lake Erie basin, the passages to Lake Chicago and the Lake Simcoe basin being still closed.

CHAPTER XXI.

GLACIAL LAKE ALGONQUIN.

By Frank B. Taylor.

HISTORICAL OUTLINE.

OUTLETS AND STAGES.

Lake Algonquin was the largest of the glacial lakes and marked the culmination of the waters controlled by the retreating ice sheet. The glacial lakes began separately in the Erie, Saginaw, Michigan, Green Bay, and Lake Superior basins, but after many changes all, except that which lay in the basin of Lake Erie, were combined in Lake Algonquin. (See Pl. XXI.)

Lake Algonquin has a very complex history, for at different times it had outlets at five different places and was affected, especially in the latter part of its existence, by extensive differential uplifts of the land. The uplifting movements were strongest in the north, the direction of maximum rise being a little east of north in the central part of the area and about north-northeast in the eastern and western parts. The establishment of the first outlet and two later changes of outlet were caused by the uncovering of lower points of discharge by the retreating ice sheet; one change was caused by differential uplift and one change was caused by the merging of Lake Algonquin with another lake at about the same level. Besides these, there were several temporary and transitional stages during which two or three outlets were active at once while the discharge was shifting from one outlet to another. The changes of Lake Algonquin can perhaps be understood best by considering them in terms of the different lake basins occupied at the successive stages and by noting the location of the outlet at each stage. This method furnishes a natural basis for dividing Lake Algonquin into four stages.

The introductory stage of Lake Algonquin was short and was followed by one or two transitional steps or substages in which different lake basins and different outlets were involved. These steps of transition are mainly matters of inference and are not based on observation. Nevertheless, their existence is not to be doubted. The first stage occupied only the south part of the basin of Lake Huron, including Saginaw Bay. It received tributary drainage from smaller lakes in the south part of the Georgian Bay and Lake Simcoe basins. Its existence is based on evidence of the establishment and erosion of its outlet through the distributaries of the St. Clair River at St. Clair, and on characters of the Niagara River and gorge. The steps of transition following this are simply physical and logical necessities, made so by the conditions of development from the first stage to the later fully developed Lake Algonquin, which included all three of the upper Great Lake basins.

The first stage, known as Early Lake Algonquin, covered only the south part of Lake Huron (including Saginaw Bay) and did not cover any part of the present Georgian Bay or of the Lake Michigan or Lake Superior basins, its contemporaries in the Michigan and Superior basins being still Lake Chicago and Lake Duluth respectively. The outlet was at Port Huron and the overflow passed south through St. Clair and Detroit rivers to the basin of Lake Erie.

When the ice sheet drew away from the high ground northwest of Alpena, Mich., it allowed glacial Lake Chicago in the basin of Lake Michigan to unite with Early Lake Algonquin. If this occurred, as it most probably did, before the opening of the Kirkfield outlet in Ontario, the two lakes were probably already at very nearly the same level at the time of union, and no considerable change of altitude occurred in either, the overflow probably being divided between the two original outlets at Port Huron and Chicago. If this was the order of events the united lake succeeded Early Lake Algonquin.

But if the union took place after the opening of the Kirkfield outlet, the waters of Early Lake Algonquin must have been lowered through that outlet, and when the union with Lake Chicago came the whole discharge must have been given to Kirkfield, leaving the outlets at Port Huron and Chicago dry. In this case the waters of the Huron-Georgian Bay-Simcoe basins fell to the Kirkfield outlet immediately after Early Lake Algonquin time, and those of Lake Chicago fell to it later. No facts yet known are decisive as to the time relations of these events.

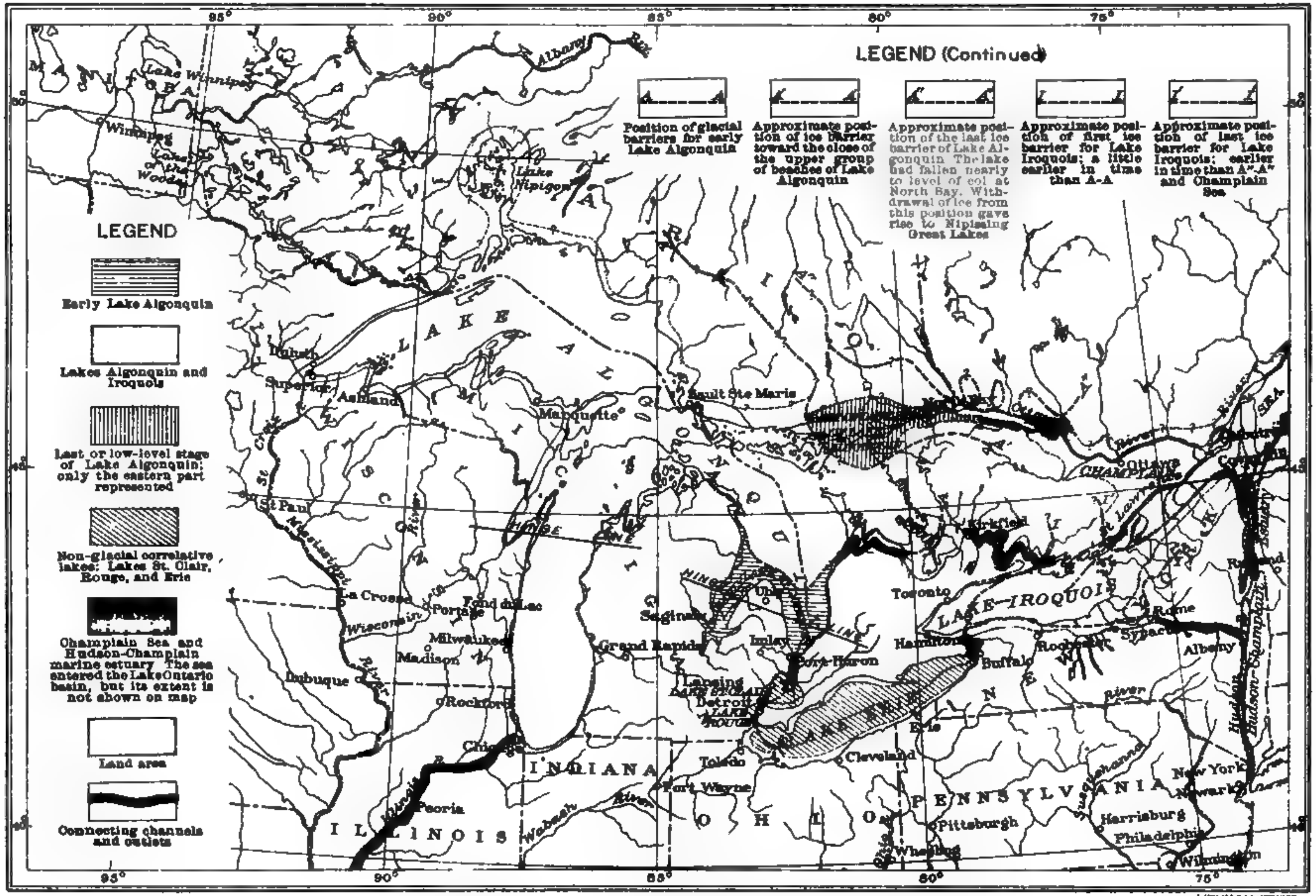
When the introductory stage of Lake Algonquin, with its complicated substages, had passed, the waters of all the upper basins—Huron, Georgian Bay, Michigan, and Superior—came to one level with the outlet at Kirkfield, Ontario, and established the second or Kirkfield stage, which endured for a relatively long time. The outlet channel at and below Kirkfield shows that it carried the whole overflow. The Port Huron and Chicago outlets were therefore dry, the level of the lake at that time being in all probability 50 to 100 feet below these outlets and below the upper Algonquin beach as now seen in the southern parts of the Lake Huron and Lake Michigan basins.

When the outlet had been established at Kirkfield for a relatively long time and the area of Lake Algonquin had become greatly expanded, the northern and northeastern parts of the Great Lakes were strongly uplifted, affecting Kirkfield greatly but having no effect on Port Huron and Chicago. It seems certain that when the Kirkfield outlet first opened it was 50 to 100 feet lower than the other two, but that when the uplift began it soon raised Kirkfield to the same level and higher, carrying the whole discharge back to Port Huron and to Chicago and beginning the third or Port Huron-Chicago stage. The outlet at Chicago was held firm by a rock sill, but that at Port Huron was composed of clay and was cut down rapidly. The overflow appears to have been largest at Port Huron from the first, and to have turned more and more to that outlet. It was during this stage that the main part of the great northern uplift took place, raising the region north of Lake Huron and Georgian Bay and most of that around Lake Superior by at least 600 or 700 feet. South of the isobase of Kirkfield the beach of the Kirkfield stage was everywhere submerged. Hence all the Algonquin beaches south of this isobase and probably some of the higher ones north of it belong either to the third or Port Huron-Chicago stage, or to the intervening three-outlet phase, when the overflow was changing from Kirkfield to Port Huron and Chicago and all three outlets were active at once.

The Port Huron-Chicago stage continued until the ice sheet withdrew from the Mattawa and Ottawa valleys and permitted the waters to escape in that direction, diverting the overflow from Port Huron and Chicago and initiating a short three-outlet or two-outlet phase, known as the Ottawa transitional stage. The waters fell until the rocky divide at North Bay became the sill over which the outlet stream flowed to the Ottawa Valley. This last event marked the total withdrawal of the ice, brought Lake Algonquin to an end, and inaugurated the nonglacial Nipissing Great Lakes.

THEORETICAL RELATIONS OF THE BEACHES.

Lake Algonquin appears to have attained nearly its greatest extent before it was affected by much uplifting or warping of the land. If during all this time it had had only one outlet and if this outlet had remained unaffected by erosion so as to keep the lake constantly at one level, then the whole extent of beach made during that time would constitute one continuous individual and, in distinction from other lower beaches of Lake Algonquin, might be truly designated as the upper or highest beach of the lake. But as a matter of fact there were, during the time preceding the great uplift, two or three changes of outlet involving at least slight changes in the altitude or level of the lake surface. Then later the great uplift produced another change, causing one outlet to be abandoned and two others to become active, and dividing the discharge between them. One or possibly both of these outlets had carried the discharge of this same lake at an earlier stage. Such changes give considerable complexity to the history of what is seemingly the highest Algonquin beach. Except at a few places (all in the far north) what appears to be the highest Algonquin beach is everywhere about the



A HOEN & CO. BALTIMORE

MAP OF GLACIAL LAKE ALGONQUIN AND ITS CORRELATIVES

By Frank B. Taylor and Frank Leverett

100 0 100 200 300 Miles

1914

same in strength, general characteristics, and relations, and yet, on theoretical grounds, it seems certain that it is not strictly the same beach at all places. The plane of the highest beach in one lake basin in all probability is slightly different from that of the highest in another lake basin and is therefore, in precise terms, a different beach made at a different time. But the planes of some of the beaches related to the different early outlets were so nearly at the same level that it has not yet been possible to distinguish them in the field. Besides, in the later, longer-enduring stages (Kirkfield and Port Huron-Chicago), the wave work on the shores was so great that the fainter, earlier beaches of Early Lake Algonquin and of the other transitional substages were probably entirely destroyed, even though some of them, especially that of Early Lake Algonquin, probably stood slightly higher. The probability of this is heightened by the fact that as the overflow gradually shifted from Kirkfield to Port Huron and Chicago the lake was rising on all the shores south of the isobase of Kirkfield and was consequently eroding more effectively than if it had been stationary, and much more effectively than if it had been falling. The area affected included all of Early Lake Algonquin, for this lake was limited to the south arm of Lake Huron and to Saginaw Bay.

What seems to be the highest beach everywhere except at some places in the far north appears to be a single, continuous individual throughout. Separate "highest" beaches for the outlets at Port Huron and Chicago have not been found. The visible "highest" beach south of the isobase of Kirkfield appears to be the beach of the three-outlet phase, when the overflow was shifting from Kirkfield to Port Huron and Chicago, and its great strength indicates either a pause or a very slow rate of change—probably two slow changes, first a slow rising and then a slow falling. Since the visible highest beach seems a unit and covers all the basins to the far north, it is convenient to speak of it as the "highest" or upper beach of Lake Algonquin, although there are theoretical reasons for believing that it really stands in the place of two or three beaches at slightly different levels. The original beach of the Kirkfield outlet was separated from the other two by a wider vertical interval, but it is wholly submerged south of the isobase of Kirkfield.

The first or early stage of Lake Algonquin filled only the southern arm of the Lake Huron basin, though it received tributaries from lakes in the Georgian Bay and Lake Simcoe basins. Whether the lake of this stage united with Lake Chicago before or after the opening of the Kirkfield outlet is not known. It is certain, however, that the shifting of the whole discharge to Kirkfield from Port Huron (or from Port Huron and Chicago) lowered the level of those parts of the lake which had previously discharged at these two outlets by 50 to 100 feet and caused both of them to go dry. If the lake changes had continued in the same order, that is, if the level of the waters had continued to fall by stages without any northern uplift intervening to bring the discharge back to the southern outlets, the beach of Early Lake Algonquin and the highest beach of greater Lake Algonquin, in the south half of the Lake Huron basin (and perhaps in the south half of that of Lake Michigan) would now be seen in distinctly separate planes.

The northern limit of the beach in the higher early plane would be determined by the position of the ice front at the time when the outlet at Kirkfield was first opened. The plane would end at one of the promontories which project northward both east and west of Owen Sound, Ontario. A similar limit for this water plane might be expected on the west side of Lake Huron somewhere on the northward slope west of Alpena, and possibly also on both sides of the northern part of Lake Michigan. All of the highest Algonquin beach north of this limit would lie in a slightly lower plane belonging to the time of the three-outlet phase.

These theoretical limits for the earlier highest water plane have not yet been recognized in field observations, but they may be at some future time, when the country in the critical areas is cleared and researches are made in greater detail. The great uplift, however, added much complexity to the relations of the beaches. In the Lake Huron basin the hinge line of the Algonquin uplift runs about N. 68° W. nearly through Grand Bend, Ontario, and a mile or two north of Richmondville and Standish, Mich. The uplift was differential and produced an effect like tilting, the direction of most rapid rise lying at right angles to the strike, or about

N. 22° E. The isobase of Kirkfield is parallel with the hinge line. The promontories near Owen Sound lie roughly 30 miles down the dip of the tilted plane from the Kirkfield isobase. The uplift raised the water against the shores of the promontories near Owen Sound until discharge was established at Port Huron and Chicago. Then as the uplift continued the level of the lake at Kirkfield and Owen Sound began to fall. Thus, some of the original difference of level between the water plane of Early Lake Algonquin and that of the Kirkfield or second stage was lost by submergence due to the tilting, increasing the difficulty of distinguishing the termination of the beach of the earlier higher plane.

EARLY LAKE ALGONQUIN.

The existence of Early Lake Algonquin is largely a matter of inference and is based (see p. 409) not on observation of its beaches or of moraines marking the position of its ice barrier but on its outlet, as shown by the distributaries of St. Clair River over the Port Huron moraine at St. Clair, and on certain characteristics of Niagara River. No beach marking the shores of this stage of the lake is known, probably for two reasons—(1) because Early Lake Algonquin endured for only a relatively short time and probably did not develop a strong shore line; and (2) because when the discharge returned to Port Huron and Chicago after having passed eastward for a long time by way of Kirkfield, Ontario, the lake was reestablished at or only very slightly below the level of Early Lake Algonquin and remained there for a relatively long time, forming a strong and relatively mature shore line and completely destroying the earlier beach. At any rate, nothing has been found which seems to represent the earlier lake.

It seems certain that the retaining ice barrier of Early Lake Algonquin barely closed the passages northwest to Lake Chicago and east to the basin of Lake Ontario (by way of the Trent Valley in Ontario), and that soon after the lake had become settled in its basin another short step of retreat opened one or both of these passages and allowed the level of the lake to fall, so as to divide the overflow with Chicago if the union with that lake came first, or so as to give the whole discharge to Kirkfield, if that outlet opened first. Even if the union with Lake Chicago came first the change of the whole discharge to Kirkfield came very soon after. Thus Early Lake Algonquin was short lived, and the Huron-Michigan stage, if it existed independently before the opening eastward to Kirkfield, was still shorter.

KIRKFIELD STAGE.

HISTORY.

The introductory, transitional stages of Lake Algonquin were short and the greater Lake Algonquin, comprising the waters of the basins of Lakes Michigan, Superior, and Huron (including Georgian Bay), was soon established with its outlet at Kirkfield, Ontario. The lake had not yet attained its greatest extent, for the ice sheet still held some of the northern part of each of the lake basins, but its condition marked the beginning of the greater lake as distinguished from the much smaller Early Lake Algonquin and the intervening transitional stages. The farther withdrawal of the ice gradually increased the area of the lake nearly to its maximum without opening any new outlet.

Late in the progress of the retreat of the ice a great movement of land elevation began, raising and closing the outlet at Kirkfield and sending the discharge back to Port Huron and Chicago and bringing the Kirkfield stage of Lake Algonquin to an end.

OUTLET.

The outlet for the Kirkfield stage headed about a mile northeast of Kirkfield, Ontario, where the outlet river passed over a sill of limestone through an extensive swamp at nearly the same level into Balsam Lake and thence down Trent River and Kawartha Lakes to near Peterboro, where it built an extensive delta of gravel in a land-locked bay of the glacial Lake Iroquois. Spencer named this Algonquin River. The scouring effects of the great river are well marked in the intervals between the several small lakes which form a large part of Trent River.

The surface of the country around Kirkfield is rather hilly, so that the approach to the head of the outlet was somewhat broken by islands and the headward part was itself crooked and very irregular. Several strong shingle beaches enter the head of the outlet, the uppermost of which keeps considerable strength for a surprising distance down the outlet. Even on Cameron Lake, which is much smaller than Balsam Lake, light gravelly beach ridges, not strong but striking for such a situation, are well formed a mile southwest of Fenelon Falls. The strength of the beaches and the erosion effects of the outlet river seem to indicate relatively long activity for this outlet. There was only a few feet of gentle descent over the rock sill at the head of this outlet, so it held the lake at a constant level. The lower fainter beaches which lead into it were probably made in the three-outlet phase, when the discharge was leaving Kirkfield and passing to Port Huron and Chicago.

BEACH OF THE KIRKFIELD STAGE.

With the passing of the transition stage, the level of Lake Algonquin became fixed by the outlet at Kirkfield; and the erosion of the outlet below its head and the strength of the beaches entering it and in its expanded parts give much reason to believe that the beaches of this stage were strong on all the shores of Lake Algonquin. These strong beaches probably continued northward to where they met the front of the ice, but as yet none of these meeting places of beaches and moraines have been found.

The large capacity of the outlet at Kirkfield makes it plain that the whole discharge passed through it. Indeed, the dimensions of the old channel indicate a somewhat larger volume than that of the present St. Clair River. The strength of the beach of the three-outlet phase seems to show that the change was gradual or that there was a considerable pause while the three outlets were active.

In the early part of the uplift, until the discharge began to leave Kirkfield, the isobase of Kirkfield was a nodal line on which the water plane swung as on a fulcrum, in effect falling at the north and rising at the south. This line runs from Kirkfield west-northwest, passing about 20 miles south of Sault Ste. Marie. On all the shores south of this line the waters of the lake were backed up and the beach previously made during the Kirkfield stage was submerged, and on all the shores north of this line the waters fell away and the beach previously made was abandoned.

It follows that the beach of the Kirkfield stage was submerged everywhere in the southern peninsula of Michigan and that, so far as this monograph is concerned, there are no beaches of the Kirkfield stage to be described, the visible Algonquin beaches all belonging to the next later stage. Outside of the area considered in this monograph there are beaches that belong to this stage, but they are in Ontario and the States bordering on Lake Superior. For the sake of comparison, however, this beach at one or two localities will be briefly described in connection with the beaches of the next stage.

At Kirkfield the upper strand of the beach stands 883 feet above sea level, or 276 feet above the Algonquin beach in the area of horizontality. But even this large uplift does not measure the full elevation that affected Kirkfield, for before the movement began the beach at Kirkfield marked a water plane that passed below the level of the Port Huron and Chicago outlets. At least 40 or 50 and possibly 100 feet must be added to the 276 feet to get even the approximate uplift at Kirkfield. This, of course, affects also the tilt rate, for this must not be based on the visible three-outlet beach which stretches from the hinge line at Grand Bend, Ontario, to Kirkfield but on the submerged beach of the Kirkfield stage.

PORT HURON-CHICAGO STAGE.

HISTORY.

The third or Port Huron-Chicago stage opened while the Kirkfield stage was closing; that is to say, when the overflow commenced at Port Huron and Chicago it began to diminish at Kirkfield, and the two stages overlapped for the time that the three outlets were active together. It follows that, not counting the introductory transitional stage, the highest beach of Lake

Algonquin throughout all the region south of the isobase of Kirkfield was made during this three-outlet phase, the northern part while the Kirkfield outlet still carried more than half the overflow and the southern part while the southern outlets carried more than half. The strong development of this beach indicates either pause or very slow uplift, although the fact that the lake was slowly rising upon the land also tended to give the waves maximum power and to make the beach strong. But although the upper beach belongs to the three-outlet phase, all the other Algonquin beaches belong to the Port Huron-Chicago stage.

The magnitude of the uplift that affected Lake Algonquin in the north is shown by the great increase of the vertical interval between the Nipissing beach, which is everywhere easily recognizable, and the highest beach of Lake Algonquin. Although this interval is only 10 feet in the area of horizontality, it widens to more than 175 feet at Mackinac Island and to nearly 365 feet at Sault Ste. Marie.

OUTLETS.

The outlets of the third stage of Lake Algonquin were at Port Huron southward to the Lake Erie basin (see p. 410), and at Chicago through Desplaines, Illinois, and Mississippi rivers to the Gulf of Mexico. The Chicago outlet has been fully described by Mr. Leverett[1] and by W. C. Alden.[2]

BEACHES OF THE PORT HURON-CHICAGO STAGE.

EARLY INVESTIGATIONS.

The stronger of the beaches of Lake Algonquin, especially the very strong highest strand and the associated heavy ridges of the upper group, were recognized as ancient shore lines and referred either to the lakes or to the sea by many of the early explorers and settlers. Bayfield, Houghton, Desor, Whittlesey, and others recognized these beaches in the Georgian Bay, northern Huron, and Lake Superior basins. Later they were studied on the shores of Lake Michigan near Chicago by Bannister[3] and by Andrews,[4] and in Wisconsin by Chamberlin.[5] But the first tracing of the upper Algonquin beach and the first accurate measurements of its altitude in the region of strong deformation were made by Spencer through independent work in Ontario, and his results brought out the first clear conception of the northward differential uplift or warping of the land and of the direction and rate of the rise.[6]

In his work Spencer used a spirit level, and the accuracy of many of his determinations has been verified by subsequent measurements made in the same way. Spencer did not trace the beach continuously across the country nor map it in detail, but identified it from place to place by certain qualities of strength and character. Nearly all his inferences as to its continuity between points of observation appear to have been correct, but one important inferred extension of the beach beyond observation was erroneous. From its high level around Lake Simcoe and Georgian Bay, Spencer showed how the beach descends rapidly, but at a decreasing rate, along the east side of Lake Huron to Grand Bend. Beyond this he inferred its extension southwestward in a gently declining plane so as to pass about 20 feet below present lake level at Port Huron. Instead of this, as the writer found a few years later, the beach becomes horizontal about at Grand Bend and passes thence into Sarnia at a uniform level of about 25 feet above the lake.

Spencer often noted the group of strong ridges close below the highest beach and occasionally made brief mention of other shore lines at lower altitudes but appears not to have undertaken to identify them from place to place or to have made many measurements of their altitude.

From 1890 to 1900 the writer carried on independent studies on the ancient shore lines of the Great Lakes region.[7] The work extended over most of the lake region and in the northern

[1] The Pleistocene features and deposits of the Chicago area: Bull. Chicago Acad. Nat. Sci. No. 11, 1897, pp. 55-64.
[2] Chicago folio (No. 81), Geol. Atlas U. S., U. S. Geol. Survey, 1902, p. 7.
[3] Bannister, H. M., Report on Cook County, Ill.: Geology of Illinois, vol. 3, 1868, pp. 240-244.
[4] Andrews, Edmund, The North American lakes considered as chronometers of postglacial time: Trans. Chicago Acad. Sci., vol. 2, 1870, pp. 1-24.
[5] Chamberlin, T. C., Geology of Wisconsin: Wisconsin Geol. Survey, vol. 2, 1877, pp. 219-229.
[6] Spencer, J. W., Deformation of Algonquin beach and birth of Lake Huron: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 11-21.
[7] See Bibliography, pp. 48-50; papers by F. B. Taylor bearing date earlier than 1900.

basins was directed chiefly to the study of the upper Algonquin and the Nipissing beaches. The importance of faint shore lines was not then fully realized, and comparatively little attention was given to the fainter intermediate lines. The value of the results of that work are somewhat marred, because the measurements were made mostly by aneroid barometer, with a few by hand level in favorable localities.

Since 1900 the work has been continued in association with Mr. Leverett, who has also made many valuable observations on the Algonquin as well as on the other beaches of this region. Although the Great Lakes history was set apart as the particular theme of the junior author of this monograph, it is a genuine pleasure for him to acknowledge that much valuable advice and assistance and many valuable data have been received by him from the senior author.

In 1891 Lawson [1] used the wye level in surveying the abandoned strands of the north shore of Lake Superior, but he assumed horizontality for all the beaches. Continuous tracing is impossible in the region in which he was working, and he appears to have made no attempt to identify any individual beach from place to place by its strength or other characteristics. This was done later by the present writer for one beach—the Nipissing—first from a study of Lawson's results and later independently.[2] Ultimately, when some of the higher beaches in Lawson's series are identified with individual beaches farther south, his results will be joined to the other areas of accurately measured beaches, and will furnish the data needed for the north shore of Lake Superior.

Lane and his assistants, Gordon, Davis, Cooper, and Gregory, made some studies on the Algonquin beach in Michigan.[3] Russell studied the Algonquin beach on the southern part of the northern peninsula.[4]

The Toleston beach of Lake Chicago was in all probability reoccupied by Lake Algonquin. This beach has been studied in detail by W. C. Alden in the vicinity of Chicago and also of Milwaukee.[5]

Goldthwait made many wye-level measurements on the Algonquin and lower beaches in Wisconsin in 1905 for the Geological Survey of that State, in western Michigan in 1907 for the United States Geological Survey, and in southwestern Ontario in 1908 for the Canadian Geological Survey, under the writer's direction in both the latter fields. Goldthwait's results have been published in several papers [6] and will be used later in connection with the discussion of the deformation of the old water planes.

SUBDIVISIONS OF THE BEACHES.

The beaches of the Port Huron-Chicago stage fall naturally into three groups.

The upper group comprises the highest beach ridge and several other strong ones and a few faint ones close below. These beaches are set close together in a compact group with small vertical intervals. South of the hinge line the Nipissing and Algonquin beaches lie close together, the Nipissing being only about 10 feet below the Algonquin. This interval of 10 feet and the beaches in it are all that visibly represent Lake Algonquin in the area of horizontality. As the upper beaches rise north of the hinge line, the interval becomes wider and the number of strands increases. The interval opens out at first very gradually and for some distance appears to be filled mainly with strands belonging to the upper group. North of Au Sable River the upper group begins to be distinct, and beyond Harrisville it is clearly separated from the lower groups. Where

[1] Lawson, A. C., Sketch of the coastal topography of the north shore of Lake Superior, with special reference to the abandoned strands of Lake Warren: Twentieth Ann. Rept. Minnesota Geol. Survey, pp. 282-289 and table facing p. 280.

[2] Am. Geologist, vol. 15, 1895, pp. 304-314. Also vol. 20, 1897, pp. 111-128.

[3] Chiefly in reports of Michigan Geological Survey on Sanilac, Huron, Tuscola, and Bay counties; see Bibliography, pp. 33-54. Also Pleistocene beaches of Saginaw County: Tenth Ann. Rept. Michigan Acad. Sci., 1908, pp. 90-98, by W. F. Cooper; Report on Tuscola County, by C. A. Davis, 1908; Report on Arenac County, by W. M. Gregory, 1912.

[4] Ann. Rept. Michigan Geol. Survey for 1904, pp. 39-105.

[5] Chicago folio (No. 81), Geol. Atlas U. S., U. S. Geol. Survey, 1902; also Milwaukee folio (No. 140), 1906.

[6] Correlation of the raised beaches on the west side of Lake Michigan: Jour. Geology, vol. 14, 1906, pp. 411-424. Abandoned shore lines of eastern Wisconsin: Bull. Wisconsin Geol. and Nat. Hist. Survey No. 17, 1907. A reconstruction of water planes of the extinct glacial lakes in the Lake Michigan basin: Jour. Geology, vol. 16, 1908, pp. 459-476. Preliminary report on measurements of altitude of the Algonquin and Nipissing shore lines in Ontario: Summary Rept. Director Geol. Survey Canada for 1908, 1909, pp. 112-114. An instrumental survey of the shore lines of the extinct Lakes Algonquin and Nipissing in southwestern Ontario: Department of Mines, Geological Survey Branch Memoir No. 10, 1910.

it first becomes distinct the upper group appears to cover a vertical interval of 25 or 30 feet. Farther north the vertical range of the upper group gradually spreads, until at Mackinac Island it is 47 to 50 feet.

Below the lowest beach of the upper group there is an interval of 25 or 30 feet apparently without beaches, below which lie the three or four beaches of the second or Battlefield group. These beaches, which are not so strong as the higher ones, have been distinguished for a considerable distance down both sides of the peninsula from the north but have not been traced to the hinge line.

Below the Battlefield beaches lies the third or Fort Brady group, consisting generally of five or six rather light ridges, as represented at St. Ignace and Mackinac Island. They lie next above the Nipissing beach and are closely set at short vertical intervals. They are entirely distinct from the Nipissing beach below and the Battlefield beaches above.

North of the Straits of Mackinac the three groups are fairly distinct wherever they are well displayed. South of the straits, however, there is more difficulty in separating them. The principal and most characteristic individuals of each group are generally easy to distinguish, but in some places the intervals between the groups are filled with faint closely set ridges whose relations to the groups can not be determined.

UPPER OR MAIN GROUP OF BEACHES.

DISTRIBUTION.

Port Huron to Port Austin.—From Port Huron to Pointe aux Barques, at the northern end of the "thumb," the Algonquin beach lies generally less than 1 mile and nowhere more than 2 miles back from the present shore. In two considerable stretches it is entirely cut away. Whether it takes the form of a beach ridge, or a spit, or a wave-cut bench and lake cliff, it is always strong.

The beach, as shown in figure 12 (p. 483), enters Port Huron as a large spit or barrier ridge projecting south along the shore from old lake cliffs at the north and ending near Elmwood Street and Gratiot Avenue. The last half mile of the spit runs southwest to the end, the main part to the north trending a little east of south. It is a gravelly, sandy beach ridge or close-set series of ridges, in many places obscured by fine sand and dunes. Its last half mile after it curves to the southwest is made up of three or four strong gravelly, sandy ridges 10 to 15 rods wide, separated by narrow troughs in some places 6 or 7 feet deep. McNeils Creek cuts through the ridges about a quarter of a mile north of the south end of the spit and runs south nearly parallel with St. Clair River for a quarter of a mile before entering it. It is possible that the spit once extended farther south and has been cut away, but no certain evidence of such a change was found. The spit was built from the north, mainly out of material derived from the cutting of the old shore north of Stevens Landing.

North of the city the ridges pass through Lakeside Cemetery, where they are buried in dunes, some of which are 20 feet or more in height. The cemetery is mainly on these dunes. Except near Port Huron and in less degree between Lakeport and Stevens Landing the gravel ridges of the Algonquin beach are largely hidden by fine sand; and the ridges themselves are composed in some places mainly of sand with only a small quantity of gravel.

From Port Huron north to Lakeport the main ridge curves gently north, being close to the lake near Port Huron, but farther north drawing back to about a mile. The gravel ridges and the strip between the main ridge and the lake are almost entirely covered with dunes and fine sand. From Lakeport to Stevens Landing, about 6 miles farther north, the main ridge runs generally less than a quarter of a mile back from the present shore and is less duney than it is farther south. The land back of it is flat clay, in places 4 or 5 feet below the crest of the ridge, and is rather poorly drained though not distinctly swampy.

From Port Huron to Lakeport the Algonquin ridges rest on a flat clay floor, which slopes very gently toward the lake and which, behind or west of the main ridge, forms a swampy lagoon 6 or 7 miles long. The swamp reaches its maximum width of 1 mile opposite Gardendale, where it is floored with peat for 2 or 3 miles north and southeast. The swamp floor is here 6 to 8 feet

below the beach ridge, and the dunes rise considerably higher. From Gardendale the depression runs southeast, narrows to one-quarter of a mile in width, and ceases to be swampy. McNeils Creek comes from the higher ground west of Gardendale and flows southeast through the swampy lagoon nearly to Port Huron before it breaks through the ridges. Near Port Huron the lagoon passes into the northern part of the city as a clay flat with more or less thin sand upon it and lies very little below the crest of the main ridge.

From the north end of the swamp to a point a mile south of Lakeport a well-defined, though rather faint shore line skirts the western border of the swamp at the same level as the main Algonquin ridge. Gardendale is on the northern extremity of an extensive sandy, gravelly deposit, apparently a thin-spread delta built into the shallow margin of Lakes Lundy and Algonquin. This delta overspreads the clay plain on both sides of Black River and slopes gently eastward and northward to the edge of the swamp. The faint beach along the west side of the marsh turns southeast at Gardendale and runs along the edge of the delta, forming for 2 miles or more a low but well-defined ridge, which descends steeply 5 or 6 feet to the swamp in front. The Pere Marquette Railroad runs on this ridge or just behind it for 2 miles southeast from Gardendale.

From its faintness in some places this back beach might be regarded as affording no certain evidence of wave action. But such action appears to have controlled the course of at least one line of drainage, carrying shore drift south athwart the course of Black River in such amount as to turn the course of that stream back of the beach at Huronia from east to south.

The back beach skirts the western side of the swamp very closely and is relatively immature when compared with the main ridge. From its position behind the main ridge, it is plain that this beach was made before the main ridge, the latter having been built southward across the shallows at a later time. The position and relations of the main ridge indicate that from Lakeport south it is a spit built mainly by shore drift from the north although probably in part also from material swept up from the pebbly clay bottom immediately in front.

From Stevens Landing for nearly 15 miles north the present lake has cut heavily into the land, the Algonquin beach has been entirely removed, and the present lake is now cutting back at a rapid rate. The lake cliff is mainly clay and is 25 to 40 feet high and vertical. At some places there is no room to walk at the base unless the lake is low and very quiet. In recent years the shore between Stevens Landing and Lexington has been retreating about 6 feet per year and in some places in Huron County (according to Lane) as much as a rod a year.[1] About a mile north of Stevens Landing the recent cutting has taken away a large part of a farm, compelling the removal of farm buildings and undermining an apple orchard. In 1904 some trees had just fallen and others had fallen two or three years before.

The exposure along the face of the cliff showed several beds of clay and some sand and sandy clay in the upper part, all horizontally bedded and overlying brownish-gray till containing some stones. In several stretches between Lexington and Harbor Beach older pre-Wisconsin till is exposed on the shore and extends below lake level. Five or six miles south of Port Sanilac the cliff has cut back into the sands of the Lundy beach, forming a bluff 40 to 45 feet high.

About a mile south of Port Sanilac, where the present shore bends a little eastward and the bluff grows lower, the Algonquin beach reappears and continues north for about 11 miles, or to within a mile of Richmondville. For most of the distance it consists of two or three sandy gravel ridges, largely covered near Forester by fine sand and small dunes.

The preservation of this stretch of the beach is probably due in part to exposures of shale along the present shore and in part to exposures of the old indurated till, both formations resisting wave erosion more effectively than the later unconsolidated clay and sandy beds.

From about a mile south of Richmondville for about 15 miles northward to a point a little south of Coopers Creek (5½ miles south of Harbor Beach) the Algonquin beach is entirely cut away. In the southern part of this interval it is cut away by the present lake, but north of a point 2 or 3 miles south of Coopers Creek it was removed by Lake Nipissing, which stood

[1] Lane, A. C., Summary of surface geology of Michigan: Ann. Rept. Michigan Geol. Survey for 1907, 1908, p. 135 and Pl. VIII.

about 15 feet higher than the present lake. In this second eroded interval both the shale beds and the old hard till are much more exposed in the bluff than they are farther south and have notably retarded wave cutting. (See p. 290.) In some places the shale cliff is 10 to 15 feet high, and the small stream beds in it are cut off abruptly at the cliff and are in effect hung up on the present shore. The old till is almost as resistant and at Forestville forms a cliff nearly 50 feet high.

From about a quarter of a mile south of Coopers Creek the Algonquin beach may be traced continuously north and west to Pointe aux Barques. Near Coopers Creek the character of the shore begins to change. Instead of the heavy cutting at the modern shore with the removal of the Nipissing and Algonquin beaches, the shore during and since the time of Lake Algonquin has been advancing lakeward on account of the cutting down of the outlet at Port Huron. The land strip remaining between the Algonquin beach and the present shore varies in width from a quarter of a mile to more than a mile and is generally covered by a steplike series of beach formations. The shallows along the present shore are wider and more of the modern beach is on or nearly on the shale. Bowlders are also more numerous along this part of the shore than farther south, and all of these agencies have combined to prevent the present lake from cutting back to the Algonquin beach.

From Port Huron to Richmondville the Algonquin beach, where not cut away, is a gravelly and sandy beach ridge or series of ridges built upon low flat ground and backed by lagoons and swamps. But from Coopers Creek northward it is for the most part a wave-cut shore, generally a well-defined lake cliff with a gravelly beach ridge at its base and a descending series of ridges with intervening bowldery floors between. The lake cliff is variable in height, generally not over 20 to 30 feet, though much higher at a few places, as about a mile southeast of Huron, where it is about 70 feet high. West of Huron, which is at the mouth of Willow Creek, the cliff is absent for a good share of the way and is replaced by a beach ridge. At Grindstone City the principal business and residence street runs along the crest of the ridge and the ground south of the ridge is a trifle lower. From Huron to Pointe aux Barques the main beach is a half mile to a mile back from the present shore, except for a mile southeast of Grindstone City, in which it lies back less than a quarter of a mile. From Grindstone City to Pointe aux Barques the main beach is generally a ridge, but it is a bench and bluff a mile southeast of Burnt Cabin Point.

The sandstone of the Marshall formation comes down to the level of the Algonquin beach about 1½ miles southeast of Grindstone City and is extensively quarried for grindstones. For 5 or 6 miles each way from Grindstone City, the main beach ridge is composed largely, in some places almost entirely, of disk-shaped wave-worn shingles of this rock.

From about a mile south of Pointe aux Barques the upper Algonquin beach runs westward more than 2 miles into the western part of Port Austin. It is not so strong here as usual, partly because it lay at the back of wide shallows where wave action was weak, but it has the same general characteristics. In the western part of Port Austin and southwestward dunes and fine sand obscure the gravel ridges.

Port Austin to Bay City.—The characters of the Algonquin beach on the west side of the "thumb" differ greatly from those on the east side. Through the entire stretch from Port Austin to the southern extremity of Saginaw Bay the land approaching the lake is very flat. The shore faces northwest over Saginaw Bay and the prevalent strong, dry onshore winds carry the sands from the shallow shore back onto the clay flats and build them into dunes or duny ridges. Lagoons and swamps lie back of the upper ridge and between the later ones. Some of the ridges are gravelly, the highest being most so. The main Algonquin beach lies half a mile to a mile back of the present shore and is a rather narrow duny belt as far south as Bayport. Farther south it splits into several parallel ridges which spread wider apart toward Sebewaing and which in places number as many as five, all having nearly the same crest height, dropping slightly toward the lake, and covering a width of 1½ to 2 miles. At several points between Port Austin and Sebewaing exposures of gravel or gravelly sand were found in the back or higher part of the Algonquin belt, and it is possible that they extend all the way but are buried under fine sand. In some places the dune knolls are well developed, reaching 20 feet or so above the Algonquin

level. The dunes associated with this beach appear not to have been blown up from the present shore, but to be as old as the Nipissing beach, some possibly as old as the later lower stages of the Algonquin.

Southwest from Sebawaing the split-up ridges of the Algonquin spread more widely after passing about 5 miles into Tuscola County and entering the extensive swamps east and south of Quanicassee.[1] They become weaker and more fragmentary on account of the very wide flats in front of them and seem to be composed of sand without gravel. Some contain a considerable amount of clay and are suspected of being in part ramparts like those associated with the Maumee beaches in Ohio. (See p. 337.) The faint upper ridges reach south into the southeast corner of Saginaw County and a few weak bars extend northwest past Munger to Bay City; but most of these fragments are not up to the level of the upper strand of the Algonquin. The divide between Saginaw Bay on the north and Saginaw and Cass rivers on the south is a low, broad ridge of clay—a water-laid moraine—of which the lower parts are distinctly below the Algonquin level. South of this ridge a sprawling, irregular-shaped basin covering the lower reaches of Cass, Flint, Shiawassee, and Tittabawassee rivers was evidently a shallow bay of Lake Algonquin. Unless some sandy ridges near St. Charles belong to it, no distinct beach has been found at the Algonquin level in this basin, though sandy areas associated with the rivers where they enter the Algonquin level seem to suggest the margin of a lake which reached up the valley of the Tittabawassee to Sanford, about 25 miles above the head of the Saginaw, and 8 to 10 miles up each of the other rivers.

Bay City to Au Sable River.—From the wide flats along Saginaw River south of Bay City a shallow and very irregular shaped depression runs northward behind or west of the main Algonquin ridge, which runs north-northwest from Bay City. It is probable that a sandy belt along the west bank of the broader part of this depression, passing through southern Monitor and central Frankenlust townships was made by the early waves of Lake Algonquin before the barrier ridge northwest of Bay City was built. It lies at about the altitude of the upper Algonquin.

A rather light, gravelly beach ridge in the cemetery in the southeast part of Bay City is apparently slightly below the upper level of Lake Algonquin. But on the west side of the river the main ridge begins again, curving from north to northwest to Kawkawlin, thence curving gradually north and slightly east of north to Pinconning. The beach here is a heavy barrier, composed mainly of fine sand, rarely with gravel and pebbles, lying 1½ to 2 miles back from the present shore, except back of Lengsville, where it is little more than a mile. Toward Pinconning and beyond, the beach is broken at shorter intervals but continues as a strong sandy and in places gravelly ridge with much sand in front of it and behind it. A few small dunes lie along the line of the main ridge.

In Arenac County the main ridge passes half a mile west of Saganing and just west of Pine River, curves a little east, and passes about 1½ miles southeast of Omer. For 2 or 3 miles northeast of Arenac, however, it is modified by the contemporary delta of Rifle River which spreads a mile or two on either side. From Arenac northeast and east the beach is considerably farther inland and more fragmentary. For 2 to 4 miles east of Omer it is a heavy gravel ridge. Eastward across Au Gres River only detached and rather weak fragments of the upper strand were found. West of Whitestone Point a well-developed continuous gravel ridge runs about a mile back from the lake northward to Alabaster, in Iosco County. Just south of Alabaster the Algonquin beach comes close to the present lake shore, mainly as a gravel ridge but at two or three places as a cut with a low cliff.

From Alabaster northward to about 1½ miles northwest of Tawas the Algonquin beach has been completely cut away, not by the present lake but by the Nipissing waves. The Nipissing and modern beaches combined form a flat about a quarter of a mile wide and the cliff increases in height from zero at Alabaster to about 70 feet and is very steep. The highest part is about 1½ miles north of Alabaster and extends north for about a mile. It is composed mainly of till, with some sand and gravel on top. Bedrock outcrops on the shore at Alabaster.

[1] Davis, C. A., Report on geology of Tuscola County: Michigan Geol. Survey, 1908, map of surface geology.

At the cemetery west of Tawas the upper Algonquin beach is a broad sandy ridge, and it runs thence north passing close along the west side of Tawas Lake and turns northeast along the base of the higher ground. The beach is here 4 to 5 miles from the lake and is separated by a great swamp from the Nipissing beach near the shore. It is mainly a broad sandy ridge, generally close to the base of a lake cliff. One or two ridges of the upper group below the highest are present at some places. The lake cliff and upper ridge crosses Au Sable River 4 miles west of Oscoda.

From Au Sable River to Mullet Lake.—From Au Sable River the upper Algonquin beach runs a little east of north, passing close west of the north end of Van Etten Lake. Thence it runs north to the north line of Iosco County and then northeast to Greenbush. In most of this interval the upper beach forms a barrier along the east side of a great swamp. Toward Greenbush it becomes a belt of strong gravelly ridges. Several of the lower members of the upper group are well developed here and for a mile or two south of Greenbush, this being the most southerly place at which they are well displayed.

Between Greenbush and Harrisville the highest Algonquin and the members of the upper group are finely developed. The highest is generally a beach ridge at the base of a lake cliff. The lower members are fragmentary in places.

At Harrisville the upper group is well developed. The highest beach is a strong gravel ridge which crosses a small ravine as a gravel bar in the northwest part of the village, but which in the southwest part has a low cliff behind it. The courthouse is on the highest ridge. The even line of the beach is the more prominent, because it is superposed upon an uneven morainic topography.

The beaches below the highest are not strong, but several can be distinguished. The village is spread over the whole series. One or two ridges near the lake are somewhat stronger, but these appear to belong to the Battlefield or Fort Brady groups.

A mile or two north of Harrisville the main highway follows the upper beach, which is a strong ridge, rather wide and flat, backed by a cliff 20 to 50 feet high. This is the usual form of the shore northward for about 20 miles.

From Harrisville to Alcona the highest Algonquin is generally a strong gravel ridge at the base of a prominent lake cliff 10 to 60 feet high. Some of the lower ridges of the upper group are fairly well developed.

From Alcona to Ossineke almost the whole slope below the highest beach is swampy. The beach lies 2 to 3 miles back from the lake and the lake cliff reaches a height of 70 or 80 feet in some places near Black River. (See Pl. XXII, *B*.) Great numbers of springs issue from the base of the bluff and also from the slope to the lake. The road going west from Black River crosses several members of the upper group of the Algonquin in a cedar swamp and ascends a lake cliff about 50 feet high.

Back of Ossineke the upper group of beaches is well developed and the old lake bluff is cut sharply into high morainic ground. For 10 miles northwest from a point about 3 miles south of Ossineke the bluff is high and bold. It ends abruptly about 2 miles west of the middle of Devil Lake, and the beach runs on straight north for about 9 miles on a wide plain of sandy gravel. At some points it is fairly well defined, but for considerable distances it is flat and sandy and its exact location is difficult to determine. The ridge runs north to the bank of Thunder Bay River, but seems to drop off slightly in altitude toward its north end.

In all probability a large shallow bay extended west of this summit ridge, one arm of it reaching 7 or 8 miles up the south branch of Thunder Bay River close behind the ridge. For 3 or 4 miles along the west side of this bay the former water level appears to be marked by a faint wave-cut bench. North of the river a spit runs southwest from the main Algonquin shore to meet the end of the ridge on the south side, as if to inclose completely the bay to the west. Northwest from this spit a faint beach inclosing a considerable swampy tract defines the irregular outline of the bay and turns up the north branch of the river. Although no shore line was found so far up, it seems certain that the waters of the bay extended up the middle branch nearly to Long Rapids. The summit ridge and the spit are crossed by the river about 7 miles northwest of

A. THE ALGONQUIN BEACH RIDGES ON THE SHORT TARGET RANGE, MACKINAC ISLAND.

B. ALGONQUIN CLIFF AND TERRACE NEAR BLACK RIVER, ALCONA COUNTY, MICH.

Alpena. On the great sand plain west of Alpena the lower ridges of the upper group do not appear continuously but may be represented by ridges that can be followed for short distances.

From the spit north of the river the upper beach runs in moderate development 2 miles southeast and turns northeast. At the turn and northeastward the upper ridge is massive and is composed of coarse gravel and shingle. West of sec. 6 (T. 31 N., R. 8 E.) it is particularly strong and has been excavated for ballast by the Detroit & Mackinac Railway. Some of the lower members of the upper group are present but are weak.

From the angle west of the corner, the upper ridge runs northeast nearly 3 miles and is well developed most of the way. Where the road crosses it in east sec. 32 (T. 32 N., R. 8 E.) it is a finely formed shingle barrier rising 15 feet or more above the ground to the south.

Northward from Alpena the drift is rather thin and limestone is exposed in many places. The beaches contain a large proportion of shingle or flat, disklike limestone pebbles. The slope below the Algonquin beach, especially below the lower members of the upper group, is very stony most of the way from Alpena to Rogers.

North and northeast of Alpena the narrow, thinly covered crest of the limestone ridge led to the formation of a point and several islands in Lake Algonquin. On some of these the beaches are finely formed gravel ridges, especially on one 4 miles northeast of Alpena mostly in the S. ½ sec. 36 (T. 32 N., R. 8 E.), where an elongated oval barrier bar incloses lower ground. Several of the lower ridges of the upper group are strongly developed on the lower slopes, especially the north and east slopes of this bar. Slightly lower ground intervenes to the point of the mainland a mile northwest, and some of the lower ridges are well developed on the north and south slopes of the sag.

Two miles east of the oval bar another small island, standing on the west shore of Grass Lake, does not reach the upper level, but is finely crowned by one of the lower beaches and is encircled by one or two fainter ones below. Two miles northeast of the oval bar a high ridge runs northeast and southwest, two parts of which rise to the height of some of the lower beaches of the upper group. The larger part lies east of the railroad spur from the cement mills and the smaller one west of it. Both are surrounded near the top by gravelly beach ridges of moderate strength and have two or three weaker ridges on their flanks. The trend of these two islands produced passes close to the island at Grass Lake. The outlet of Long Lake flows close along their north side, at the base of a rather steep descent of over 100 feet. Aneroid readings indicate that the two islands fall a little short of the highest Algonquin level.

From 5 miles north of Alpena the upper Algonquin beach runs 26 miles northwestward with only trifling deviations from a straight line to a point 1 mile south of Crawford's quarry. The upper beach is well developed through most of this distance and the lower members of the upper group are well displayed in a number of places. Near the south end of Long Lake, about a mile southwest of Summerville, the upper beach and some of the lower members are finely developed. Wave action was apparently particularly effective here because the descent from the beaches to Long Lake is quite steep and the water was deep close to shore. Four miles northeast of this locality on the land between Long Lake and Lake Huron a high knoll appears to record at least two of the upper Algonquin beaches, but does not reach the highest level. Along the west side of Long Lake one of the lower beaches of the upper Algonquin group forms a fine bar a mile east of the highest ridge.

At the northwest end of Long Lake the beach is irregular and broken on account of the roughness of the country but is well formed at most places. The upper beach runs west for 2 miles from the lake and then turns sharply north. A mile north of the turn an island about a mile long, apparently belonging to the highest Algonquin level, lies about half a mile east of the main shore line. From its southeast end a gravelly spit runs southeast over half a mile and from its northwest side a low bar runs northwest about 1½ miles to the main beach.

Northwestward the upper beach passes around the west side of Lake Augusta. From the angle west of Long Lake to the northwest side of Lake Augusta, it is considerably weaker than usual, apparently owing to the formation of a great gravel bar on a low, broad ridge which stands about at the highest Algonquin level on the east side of the lake. This ridge forms the east side

of a trough 1 to 2 miles wide, which holds Lake Augusta in its northern part, Long Lake in its southeast prolongation, and Monaghan Creek, which flows southeast into Long Lake from near Lake Augusta. The ridge falls off in altitude gradually to the southeast, but from a point 1 mile north of Lake Augusta the heavy Algonquin gravel bar runs upon it for about 5 miles southeast, or within 2 or 3 miles of Long Lake.

Where the road crosses the upper Algonquin beach 2½ miles east of Hagensville the highest beach is very strong and is composed mainly of coarse gravel. About half a mile southeast of this point it becomes a fine barrier ridge with a swamp behind it, and it continues thence southeast in strong development nearly to Lake Augusta, where it turns sharply northeast and forms a high barrier bar across low ground for more than a mile. It then joins the great gravel bar on the eastern ridge and, after running east for nearly 2 miles, turns south and southeast along the crest of the ridge, as described above. Its development is very impressive, spits and bars of such proportions being seldom seen.

From east of Hagensville the beach continues northwest as a rather strong gravel ridge at the base of a wave-cut bluff 10 to 40 feet high. The lower ridges of the upper Algonquin group are well developed in this stretch southeast from Crawford's quarry.

A mile south of Crawford's quarry the highest beach turns back sharply to the southwest and then resumes its northwesterly course. The lower members of the group are finely developed in this vicinity and to Trout River, 3 miles west of Rogers, beyond which for 7 or 8 miles the upper beach is a lake bluff 30 to 100 feet high cut by the waves in a heavy morainic deposit. The upper beach runs in moderate strength along its base and the lower beaches are finely developed on the lakeward slope.

This great bluff ends about 4 miles southeast of the landing at Hammonds Bay, and the upper beach runs thence directly westward as a great high bar or spit of rather sandy gravel on the summit of the morainic ridge for over 5 miles and terminates about 4 miles north of Ocqueoc. Between it and the lake the lower members of the upper group are finely developed, although more sandy than in the places previously described.

South of this great bar the Ocqueoc River valley was a bay measuring about 4 miles each way. From the end of the clay bluff, where the spit branches off, the highest Algonquin beach turns inland and runs south 3 or 4 miles in weaker form, curving gradually to the west and northwest. It passes through the village of Ocqueoc and continues northwest about 3 miles, where it turns south and runs about 3 miles up Rainy River. After crossing this river it again turns northwest and passes within about a mile of Black Lake. From the great spit to this point the upper beach is considerably weaker than it is farther east. This is due to its distance inland from Lake Huron and to the wider shallows that approached it. Some of the lower members of the upper Algonquin group were seen in this interval, but they are weak.

Along the south side of Black Lake, however, the upper beach runs about 4 miles in considerable strength and the lower members of the group are well developed. From the southwest corner of the lake the upper beach turns south and then southeast up Black River to about 2 miles southwest of Onaway. Returning on the west side, it passes through Tower. Some of the lower members are developed in the stretch near Black Lake, but the rest of this valley is filled with sand and the lower members do not appear. From Tower the upper beach runs in a nearly direct line northwestward to a point within 2 miles of Mullet Lake. For some distance from Tower the beach marks the upper edge of a sandy plain and is not so clearly developed as usual, but toward Mullet Lake it gains in strength and becomes a prominent lake cliff, on the northward and westward slopes of which the whole series is finely developed. This locality is about 1½ miles southeast and 2 to 3 miles south of Aloha on Mullet Lake.

Along the northeast side of Black Lake, 1½ to 2 miles from its shore, a high morainic ridge about a mile wide runs about 5 miles northwest to Marsh Lake. It was a high, prominent island in Lake Algonquin, on which the beach is marked by a bench and a high lake cliff along its northeast and southwest sides. At some points the cliffs are nearly 100 feet high and some of the knobs of the moraine rise nearly 200 feet above the beach. Two or three of the ridges below the highest are well defined on the north side of the island and run for several miles north-

west toward Cheboygan. The upper beach and some of the lower ridges are also well developed on the south side, especially toward the southeast, where a great spit curves south around the east side of Black Lake.

Mullet Lake to Petoskey.—From the point south of Aloha the upper Algonquin beach runs south past Silver Lake and, after forming a small embayment reaching a mile to the east, runs west to near Pigeon River, up which it extends south for 3 miles. The highest beach and several members of the upper group are well developed where they turn toward the south around a high knoll. From Pigeon River they run west in fairly strong development to a point near the bank of Sturgeon River over 3 miles south of the village of Indian River. Here the upper beach turns south to Rondo and after crossing Sturgeon River runs northwest in a nearly direct line for about 7 miles. The beach here lies at the back of a great sandy plain and is not strong. It then runs west in an irregular course, passing a mile south of Pickerel Lake, and turns southwest past Epsilon, leaving a large knoll as an island a mile north of this place. Southwest of Epsilon the beach runs a mile or two up a trough leading south and then turns northwest to the high headland 2 miles south of Conway, where it turns southwest. After turning the shoulder of the headland the beach grows stronger toward the southwest. It is mainly a wave-cut bench and cliff facing northwest over Little Traverse Bay and Lake Michigan, but back of Bay View its lower members are considerably obscured by wind-blown sand.

Archipelago north of Indian River and Petoskey.[1]—At Indian River the waters of Lake Algonquin entered a region of islands forming an archipelago of considerable extent. The eastern islands are relatively small. One lying about 2 miles northeast of Indian River and another about 2 miles north near the east shore of Burt Lake are each about 2 miles in length and roughly oval in form. They rise 100 to 150 feet above the highest Algonquin beach, which is well developed around their sides. The lower members of the upper group are also present in moderate strength.

An irregular island or chain of islands running northward 4 or 5 miles from Topinabee on Mullet Lake shows well-formed beaches on its west side. A much larger island, 3 to 4 miles wide, begins about half a mile from Mullet Lake and extends northwestward about 7 miles to Douglas Lake. Around its east and southeast end the water was deep and gave effective action to the waves, and the upper Algonquin beach and the lower members of the upper group are strongly developed. Around the other sides the upper beach is weaker on account of wide shallows and most of the lower members are absent except to the north.

A smaller island north of this one extends as a narrow ridge about 4 miles long from northwest to southeast. It carries several of the lower beaches of the upper group and has the upper beach finely formed on its north and east sides. A spit runs northwest about 2 miles from its north end, and several lower members of the upper group appear as fine gravel bars a mile northeast of the island and 2 miles north of the westward spit. A short spit runs out also from its southeast end. A mile or two east of the south end of this island a small area is surrounded by one of the lower members of the upper group strongly developed. The bar northeast of the island is 2 or 3 miles long, and the one 2 miles north of the westward spit is about 4 miles long and bounds a large swamp lying to the south.

The bar curves westward and connects with the Algonquin beaches at the north side of Carp Lake. The highest Algonquin appears not to be represented at this place, but several of the upper group below the highest are strongly developed. One extends as a great gravel spit for about 2 miles around the east end of Carp Lake, and others extend westward and southward around the west end.

About 2 miles south of Carp Lake a chain of morainic knolls runs southeast past Buckhorn nearly to Munro Lake. Along their north side the upper Algonquin beach is finely developed, generally as a gravel ridge accompanied in one or two places by a lake bluff 30 to 40 feet high. Toward the west this island is tied to the north side of a much larger island by a great bar of coarse gravel through which the Grand Rapids & Indiana Railway is cut 2 miles north of Levering.

[1] The distribution of the islands and of the beaches among them is shown on the large colored map (Pl. VII).

About 3 miles east of Pellston the upper beach runs in moderate strength, mostly as a wave-cut bluff but in places is a gravel ridge, around a high island about 3 miles long and over a mile wide. A plain of outwash gravels extends eastward from this island, and along its north edge a heavy bar facing over Douglas Lake, apparently representing the upper Algonquin beach, extends across between Douglas and Burt lakes to join the north end of Topinabee Island and the larger island to the north.

East of Alanson and filling most of the space between Burt Lake on the east and Pickerel and Crooked lakes on the west, the upper Algonquin beach is finely developed around the sides, especially on the north and east sides, of an island 3 or 4 miles in length and breadth.

Three larger islands are set close together in the area north of Crooked Lake and Little Traverse Bay and west of the Grand Rapids & Indiana Railway. They are barely separated from each other by swampy troughs at or slightly below the upper Algonquin level. The opening of each trough is bridged across by a bar of the upper beach.

The northern island of the three lies between Levering on the east and Canby on the west and between Ely on the south and the long straight stretch of the upper beach which runs about 8 miles west-northwest from the tie bar 2 miles north of Levering. This may be called Levering Island.

The upper beach is very irregular in its course and weak in its development along the east side of Levering Island, both on account of the protection of the islands to the east and south and to the shallowness of the water. Along the north and west sides the whole series of Algonquin beaches is developed in great strength and fine form. These shores were exposed to the severest storms from the north and west, and their shore lines are particularly fine around the most northerly point 2 miles south of Sucker Creek and around the embayment of Wycamp Lake. A strong bar ties this island to the western island on the south side of this bay.

The other island east of the main trough is pear shaped, with its pointed end at Ely on the north and its base along the north side of Crooked Lake. Brutus and Alanson are on its east side and Pleasant View on its west. It may be called Brutus Island. Despite its protected position and the shallowness of the water along its east side the upper beach is quite well developed. Toward Alanson and north of Oden and Conway the Algonquin upper group is developed in great strength. Between Alanson and Oden heavy cuspate bars were formed at several levels by the shore drift from the west and north.

The western (Readmond) island is the largest of the three, filling the entire space between Little Traverse Bay and Wycamp Lake and between Lake Michigan and the trough that runs north and south from Pleasant View. This island measured 14 miles from north to south and about 8 miles from east to west. Around its north, west, and south sides the upper group of Algonquin beaches is displayed in great strength and typical form, except where it has been cut away by the lake at lower levels. The best-preserved parts are between Middle Village and Canby. From 2 miles north of Middle Village to the head of Little Traverse Bay the lower members of the Algonquin group have been mostly cut away. For 2 miles southeast of Appleton and for a short distance east of Harbor Springs the upper beach has been cut away, in both places by the Nipissing waves. Just back of Harbor Springs a trough coming from the north is barred by the highest Algonquin beach of coarse gravel and sand, which is 100 yards or more broad and stands about 15 feet above the valley back of it. This spit now ends abruptly on the edge of the steep bluff which rises 100 feet above the Nipissing beach, but at one time it apparently extended farther east.

Mackinac and near-by islands.—Mackinac Island,[1] which lies about 15 miles north of Levering Island, splendidly displays all the beaches from the upper Algonquin down. The upper Algonquin group is as well displayed here as at any other locality known, five very strong beaches next below the highest being well displayed on the short target range back of Fort Mackinac, and the highest beach, 40 or 50 rods farther north, being followed by the road from

[1] Some of the beaches on Mackinac Island were described by the writer in 1892 (The highest old shore line on Mackinac Island: Am. Jour. Sci., 3d ser., vol. 43, 1892, pp. 210-218).

Skull Cave. Several weaker ridges appear among the stronger ones on the short target range. (See Pl. XXII, *A*, p. 420.)

The ancient island—the part which was an island at the time of Lake Algonquin—rises about 80 feet above the upper beach and is about three-quarters of a mile long from northwest to southeast. It is roughly triangular in shape, tapering to a sharp point both at the north and the southeast. The entire upper group of Algonquin beaches is crowded close together on its south side and is spread out to a width of over a mile on its west side. On the east side the island was heavily eroded at one of the lower levels of the upper Algonquin group (apparently the level of the fourth or fifth strong beach below the highest), being deeply cut into a cliff 70 to 80 feet high and three-quarters of a mile long. (See Pl. XXIX, *A*, p. 453.) One or two of the strong ridges run along the outer edge of the beach made at this time. The cliff is largely composed of brecciated and recemented limestone with a few feet of stony till at the top. Near where they start away from this cliff all the beaches are uncommonly coarse in their composition, even including bowlders of considerable size, but toward the west, as seen in the gravel pit just west of the cemeteries, the gravel grows much finer and the pebbles well rounded.

Neither Round nor Bois Blanc islands were high enough to record any of the upper Algonquin group. The high ground south of St. Ignace barely reached the lowest of the upper group, but Gros Cap, 4 miles west of St. Ignace, is higher and two or three of the lower members occur on it. Three to four miles north of Hessel two or three islands in Lake Algonquin show the whole upper group well developed on their flanks. These have been called the Munuscong Islands and were described by the writer[1] and more recently by Russell.[2]

Beaver Island.—In the south part of Beaver Island, which lies in the northern part of Lake Michigan 30 to 40 miles northwest of Charlevoix, a morainic tract about 4 miles long from northeast to southwest and 1½ miles wide rises considerably above the highest Algonquin beach. On the north, west, and south sides of this ancient island the Algonquin beaches have been explored in part and all of them are unusually well developed. High Island, 4 miles west of Beaver Island, records several of the lower ridges of the upper group but apparently not the highest. None of the other islands of that group rise to the Algonquin level.

Petoskey to Traverse City.—In the east part of Petoskey the bluff disappears and the upper beach takes the form of an ill-defined terrace in passing through the town. But near Bear Creek in the southwest part a strong barrier ridge of coarse gravel spans the narrow valley of the creek, except where the stream passes through, and runs on westward less than a mile from the present shore. The level of Lake Algonquin probably extended several miles up this valley. A mile or two west of Petoskey the upper beach again takes the form of a wave-cut bench and lake bluff for about 7 miles. About 5 miles out it crosses the valley of Bear Lake as a heavy barrier ridge close to the north end of the lake. But Bear Creek, which is the outlet, passes out of the southeast end of the lake and flows north about 8 miles before reaching the bay.

South of Bay Shore, 2 miles west of the north end of Bear Lake, another depression running south to Hortons Bay on Pine Lake is crossed by a fine barrier ridge which rises 25 or 30 feet above the trough back of it. The depression is rather narrow at its north end and the barrier curves sharply north on the west side. For the next 2 or 3 miles to the west the beach lies a mile north of the highway and is largely on bedrock; it is not very strong and its materials are mainly shingles and slabs of limestone. At Burgess it grows stronger and runs south on the east side of Susan Lake. On the west side of this lake the remnant of a drumlin has a well-formed beach on its west side, and from this a fine barrier bar of gravel runs more than a mile southeast around the south end of Susan Lake.

The waters of Lake Algonquin extended up the valley of Pine Lake to Boyne Falls and 7 or 8 miles up the valley of Jordan River to a shallow divide south of Finkton, beyond which small streams flow northwest to Intermediate Lake. The lake waters crossed another low divide extending west from the south arm of Pine Lake to the north end of Intermediate Lake

[1] Taylor, F. B., The Munuscong Islands: Am. Geologist, vol. 15, 1895, pp. 24-33.

[2] Russell, I. C., A geological reconnaissance along the north shore of Lakes Huron and Michigan: Ann. Rept. Michigan Geol. Survey for 1904-5, p. 85.

at Ellsworth. The Algonquin waters extended thence down Intermediate Lake and over Grass, Clam, Torchlight, and Elk lakes to the basin of Grand Traverse Bay. They also crossed the narrow neck of land to the same basin at the north end of Torchlight Lake. At least four large islands were thus inclosed by these winding channels, the largest lying west of Pine and Intermediate lakes and extending about 26 miles, from Clam Lake to Charlevoix.

Distinct shore lines around Pine Lake mark the highest Algonquin beach and some of the lower members of the upper group. The upper line is distinct north of Undine and Hortons Bay, and several of the group are well developed near Ironton and along the railroad 2 to 4 miles south of Charlevoix. In the narrower channels to the south no beaches were found, but the swampy cols below the level of Lake Algonquin are well defined.

The highest Algonquin beach is well developed about 2 miles southwest of Charlevoix, whence it runs nearly direct to Norwood and thence south to Eastport. The lower members are well developed near Charlevoix and nearly to Norwood, but at the latter place some of them are probably cut away. Along the narrow peninsula southward from Eastport and on the east side facing Torchlight Lake the upper beach is only moderately strong. A mile and a half south of Elk Rapids the upper beach is marked by a strong gravel ridge and a hooked spit, and one or two of the members below it are faintly developed. It runs thence south close to the shore of East Arm, much of the way as a wave-cut bench and bluff, in which form it passes south onto swampy flats.

The Old Mission Peninsula, which divides the south part of Grand Traverse Bay into two parallel arms—East and West—was a long, narrow island with a rather irregular outline in Lake Algonquin, and the present land connection to the south is distinctly below the upper Algonquin beach. Three small islands were associated with it. A tiough a mile wide runs northward from Old Mission across the outer part of the point and makes another island about 2 miles long and a quarter of a mile wide on the east side. At Neahtawanta there was an island half a mile long and a quarter of a mile wide, and there was another of about the same size on Marion Island. All of these islands in Lake Algonquin are well defined by the highest beach which surrounds them by benches or ridges.

Traverse City to Northport.—In Traverse City the beach is nearly a mile back from the shore and is not well defined. West of the town, however, it lies close to the present shore and is quite distinct. It turns northwest up the trough which passes through to the south end of Lake Leelanau, but the divide in this trough appears to be a few feet above the Algonquin level.

From Traverse beach to Northport the upper Algonquin beach is close to the present shore and is well defined, except where it runs back 2 miles to the south in the embayment at Suttons Bay. At Omena a knoll a mile east of the main shore line formed a small island. Some of the lower members of the group are well developed in this interval. In the south part of Traverse Bay, however, the upper Algonquin is so little above the Nipissing beach that the lower members of the upper group are not well displayed. In the village of Northport the upper beach and two or three of the lower members are fairly strong. About a mile north of Northport the upper beach turns directly west across the peninsula.

Northport to Manistee.—Southwest of Northport the Algonquin beach enters a new province—a province of truncated headlands and landlocked bays—which extends southward along the east shore of Lake Michigan to the northwest corner of Muskegon County. Landlocked bays or shore lakes continue down to Saugatuck, but the truncated headlands are not prominent south of Oceana County.

A mile and a half northwest of Northport, where the highest Algonquin beach ends abruptly at a high lake cliff, the entire series of older beaches has been cut away by the modern lake and a great fresh bluff of clay 50 to 100 feet high forms the shore. At Gills's pier the Algonquin beach is present and runs southward up the east side of Lake Leelanau. It is strong and distinct to the vicinity of Provemont, but south of that is mostly only a faint wave-cut bench. North of the outlet at Leland the Algonquin beach is fairly well defined on the east side of a morainic ridge for 2 miles but is entirely cut away on the west side. A mile south of

Leland the same condition is repeated, but the high ground is only a mile long. South and southeast this small remnant is tied to the mainland by strong Algonquin bars.

The Fox Islands, 15 miles northwest of Northport, have not been visited, but a distant view indicates that they do not rise to the level of the highest Algonquin beach, except in dunes.

North Manitou Island is a high morainic mass, nearly all of it rising above the upper Algonquin level. Only the southern end is below it. The Algonquin beach is well developed on the southwest side. At the landing on the east side it is sandy and ill defined but has a low cliff behind it. Toward the north it is gravelly and stronger and toward the south it is marked by a high lake bluff. South Manitou Island is also nearly all above the Algonquin level and the beaches are finely developed on the east side around the harbor.

South of Good Harbor, on the mainland, the Algonquin beach runs over 4 miles inland around the south side of Lime Lake and around Bass Lake, 2 miles to the northwest. Both of these lakes were locked in by Algonquin barrier bars.

The great headland at Pyramid Point was an island in Lake Algonquin. The Algonquin beach appears on its south and east sides, but has been entirely cut away on its west and northwest fronts. Another island lay just south at Port Oneida and was cut off at its north end. The beautiful Glen Lake is surrounded by the Algonquin beach quite distinctly developed. At the north this lake was shut off in part by Algonquin bars, and a trough which runs northwest from its western end is now buried under great dunes which extend northward to Sleeping Bear Point. From the north side of Glen Lake a high ridge runs northwest past Glenhaven to where it is cut off at the present shore and forms the foundation under the great dunes. The Algonquin beach is a wave-cut bench and lake bluff on the north side of this ridge and projects as a strong, high spit eastward from it. South of the west arm of Glen Lake another truncated headland presents a high bluff for 2 miles. Then for 3 miles north of Empire the Algonquin beach is finely developed at the back of a shallow embayment. For 2 miles south of this place the Empire bluffs present another great truncated headland, where the beaches are all cut away.

From Aral the Algonquin beach runs south about 8 miles on the east side of the Platte Lake embayment, the head of which is a little west of Honor. Here it turns and runs west about 8 miles to the present shore a mile north of the west end of Crystal Lake. The Algonquin beach is well developed on both sides of this embayment, especially in its outer parts near Lake Michigan. Gravel ridges and bars are developed in fine forms westward from the south side of Platte Lake.

A high drift ridge on the south side of Crystal Lake and a lower one on the north side run out to the present shore. Both were cut off by the Algonquin waves, and the north one has been truncated by the present lake. At the east end of Crystal Lake the upper Algonquin appears as a great, flat, barrier ridge spanning the head of the valley at Beulah. Evidently the west end of Crystal Lake was not closed when this beach was made.

At Frankfort the embayment entering from Lake Algonquin was small and narrow and the beach is poorly formed, the highest being either absent or not clearly marked.

At Northport and Leland the lower members of the upper Algonquin group are generally represented by from one to three or four ridges below the highest. But the interval above the Nipissing beach grows less toward the southwest and from the vicinity of Platte and Crystal lakes south the exposures are poor and the upper group is represented by only one or two faint ridges close below the highest; probably by only one, for the Battlefield and Fort Brady groups are in all probability represented by the first and second ridges above the Nipissing. Farther south the only strong Algonquin is the upper one, and this being only 10 to 12 feet above the Nipissing leaves little room for the lower ridges of the upper group.

Between Northport and Frankfort the headlands are still pronounced salients, though truncated, and the shore lakes locked in by bars are relatively large. On this stretch of shore the Algonquin, Nipissing, and modern lakes have done their shore work at distinctly separate levels and the reduction of the shore to a nearly straight line has not been accomplished.

Southward from Frankfort the conditions were somewhat different. The headlands were not so long nor the embayments so deep. The nearness of deep water to the present shore

precludes the supposition that the headlands were so long as those farther north. The freshly undercut bluffs are longer and the embayments between them are relatively small and shallow, apparently only the heads of somewhat longer forms.

Nevertheless, the wave erosion on this shore has been more effective in straightening the shore than it has been farther north, for the Algonquin, Nipissing, and present lakes have all worked more nearly at the same level, or within a vertical interval of 25 feet. Besides, during at least two low stages shore erosion was carried on at a lower level than now, and unless those stages were very much lower they must have contributed to the same result.

South of Frankfort in the small embayments at Herring Lake and Arcadia, the Algonquin beach is moderately strong. High bluffs of freshly eroded clay fill the shore intervals between these embayments, one south of Arcadia being over 6 miles long. But the embayments of Portage Lake at Onekama and of Bar Lake 4 miles north of Manistee show nothing above the Nipissing level. (See p. 456.) At Manistee the embayment seems to have been somewhat protected and the beach is weak.

The Glenwood and Calumet beaches of Lake Chicago seem to rise northward north of Grand River and terminate in the great sandy plain 8 or 10 miles south of Ludington, but the Toleston beach remains horizontal. It seems to have the same altitude and in fact to be continuous and identical with the Algonquin beach north of Manistee. The Algonquin beach appears to come to a horizontal attitude about at Herring Lake, where it is thought to pass into the same plane as the Toleston beach. (See p. 356.)

West and south shore of Lake Michigan basin.—Except where it has been washed away by the modern lake, the highest Algonquin beach has been identified and traced with almost complete continuity along the entire western shore of Lake Michigan and around its south end (in the southern half under the name of the Toleston beach). In the interval between Sheboygan, Wis., and Cooks Mills on the northern peninsula of Michigan the writer made a reconnaissance of the old shore lines in 1893, but this same district and the shore southward to Chicago has been studied since that time in much greater detail, by Goldthwait in particular. Goldthwait's measurements and those of Hobbs on the Garden Peninsula were made instrumentally. Farther south the beaches of Lake Chicago, including the Toleston (Algonquin) beach, have been studied by Leverett, Alden, and Goldthwait, and their extent and relations to the Chicago outlet have been fully determined.

Ontario.—Detailed work and instrumental measurements have also been made in Ontario, from Sarnia to the base of the Saugeen Peninsula at Wiarton and thence along the south side of Georgian Bay, around Lake Simcoe, and on the Penetang Peninsula. These studies also include the region of the outlet at Kirkfield and extend some distance down the ancient Algonquin River. The earliest work in this region was done by Spencer in 1887 and his measurements were instrumental. Later, several studies of a somewhat desultory nature were made by the writer. In 1908 an instrumental survey and further detailed studies were made by Goldthwait and the writer. The highest Algonquin shore line is finely developed throughout this area and the whole of the upper group is well displayed at many places, especially along the south side of Georgian Bay and on the Penetang Peninsula.

Lake Superior basin.—On the north side of Lake Superior, from the international boundary to Heron Bay, at the northeast angle of the lake, instrumental measurements of the shore lines were made by Lawson in 1891. His work in all probability covers some of the Algonquin ridges, but they have not yet been identified with certainty.

Lawson also examined the slope north of Sault Ste. Marie, Ontario. At this locality the highest Algonquin and several heavy ridges below it are clearly identified as members of the upper group. From the fact that it lies directly in the line of dip of the Algonquin water plane through the Straits of Mackinac and down the east side of Lake Michigan, this locality is of great importance. Since Lawson's work it has been visited by the writer and more recently by Mr. Leverett, who found that all the beaches from the highest Algonquin down were finely displayed. The Algonquin group is best displayed at Root River, 6 miles north of Sault Ste. Marie and the highest strand is there 435 feet above Lake Huron. This locality overlooks the

region south of St. Marys River and the lower ground of the northern peninsula of Michigan, and a view from it gives a very vivid impression of the great magnitude of the change in the relation of the lake waters to the land and of the recentness of that event. But that the change is really due almost wholly to differential elevation of the land rather than to the giving way of a barrier is a conception which it is not easy to visualize. Here, also, Lawson's work was instrumental.

On the northern peninsula of Michigan as far west as Houghton, the Algonquin beaches have been identified at several places by Mr. Leverett. Farther west in Michigan, Wisconsin, and Minnesota the glacial features and old lake strands are now being studied by him in preparation for a report on the Lake Superior region. In the western part of the basin the highest beach of Lake Algonquin has not yet been certainly determined.

The reconnaissance of the writer in the highlands east of Georgian Bay and in the Mattawa and Ottawa valleys included in all probability some of the members of the upper Algonquin group, but did not establish the identity in the north of the highest Algonquin of the southern part of the Lake Algonquin area.

In the region north of Michipicoten Bay, gravelly ridges found by Coleman lie very close to the plane of the highest Algonquin produced from the south. One locality at Gondreau Lake 20 miles west of Missinaibi, may possibly establish the extension of the higher levels of Lake Algonquin to that place.

The highest Algonquin beach at Sault Ste. Marie, at places on the northern part of the northern peninsula of Michigan, and on Keweenaw Point are north of the isobase of Kirkfield, and are therefore, in all probability, parts of the highest beach of the second or Kirkfield stage, and are not strictly the same beach nor in the same plane as the highest Algonquin south of the isobase. Nevertheless, nothing corresponding to this theoretical difference was seen in the beaches at Sault Ste. Marie to distinguish them from those at Mackinac Island, except that the vertical interval covered by the upper group as a whole is somewhat greater than at Mackinac. Perhaps the site at Root River was still covered by the ice sheet when the Kirkfield outlet was abandoned. These northern beaches would then belong to the third or Port Huron-Chicago stage. No facts having a decisive bearing on these relations are known at the present time.

ALTITUDE.

Progress of investigations.—The upper group of Algonquin beaches, especially the highest beach, shows the greatest amount of deformation by differential elevation of any beach in the region of the upper Great Lakes. In his early work on the beaches in Ontario, Spencer used the spirit level. Since that time, however, most investigators, including Mr. Leverett and the writer, have used only the aneroid barometer and the hand level, and though results obtained by these last two methods are serviceable for general purposes they are not accurate enough to settle the relations of the planes of the different beaches or to determine the variations in the rate of inclination of those planes.

In 1905 Goldthwait made a detailed wye-level survey of the Algonquin and lower beaches on the Wisconsin shore of Lake Michigan that served to correct some of the writer's earlier work with aneroid and hand level. In 1907, under the writer's direction, Goldthwait made a similar survey of the Algonquin and lower beaches on the east side of Lake Michigan extending from the ancient Munuscong Islands north of Hessel to Holland. In 1908 he continued the work under the writer's direction on the same beaches in Ontario, covering the east side of Lake Huron, the south side of Georgian Bay, and the region of Lake Simcoe.

Hobbs made instrumental surveys on the beaches of the Garden peninsula on the west side of Lake Michigan in 1907,[1] and Gregory in the same year ran several lines across the beach series on the west side of Lake Huron between Rogers and Harrisville. Gregory's report has not yet been published, but in a brief summary of his work, communicated personally, he describes the beaches by groups or "series" rather than by individuals, and does not always clearly distinguish the different series, putting certain beaches into the first series in some

[1] Hobbs, W. N., Late glacial and postglacial uplift of the Michigan Basin: Publ. 5, Geol. ser. 3, Michigan Geol. and Biol. Survey, 1911.

localities and into the second series in others. On this account some of his measurements on the lower members of the series are used with a reservation of doubt as to the accuracy of the identification.

In 1912 Mr. Leverett made wye-level surveys of the Algonquin and lower beaches on St. Josephs Island, Ontario, and along several lines in the northern peninsula of Michigan.

Deformation of the upper Algonquin beaches.—Spencer's surveys and Goldthwait's later work have put the discussion of the deformation of the beaches upon a much better basis than formerly. Though more detailed work might seem desirable, the increased expense would hardly be justified for the whole field in the present stage of investigations. In all probability the need of more detailed work in certain limited critical areas will be brought out more clearly by these and other similar surveys in the near future.

Besides a higher degree of accuracy in general for determinations of altitude, Goldthwait's work has afforded a stronger, safer basis for the identification of individual beaches or water planes from place to place and has led to an important modification of views formerly held as to the relations of the weaker beaches which lie in the interval between the Algonquin and the Nipissing. At Mackinac Island the vertical interval between these two principal shore lines is about 180 feet. But it narrows southward to only 10 feet in the area of horizontality. It was formerly thought by some investigators, including Mr. Leverett and the writer, that the Battlefield and Fort Brady beaches, which are displayed in this interval in the north, were related to an eastward outlet to the Ottawa Valley and hence did not converge to the same hinge line as the Algonquin. But though Goldthwait did not trace these beaches down to the hinge line, he traced the Battlefield beach far enough to show clearly that its plane converges with the upper Algonquin beaches toward the hinge line. The proofs are not so clear for the Fort Brady beaches, but the facts in hand seem to indicate that they converge to the same line.

The members of the upper group of the Algonquin beaches also converge southward toward the hinge line. The altitudes of the highest Algonquin, where determined by wye-level measurements on the east side of Lake Michigan, are given below. The first three measurements are at localities farther north and are introduced to show the continuation of the tilted plane. (See Pl. XXIII.) The altitude of Lakes Huron and Michigan is taken to be 581 feet above sea level in all the following tables:

Wye-level altitudes of highest Algonquin beach on the east side of Lake Michigan.[a]

Locality.	Altitude above sea level.	Height above Lake Huron.	Authority.
	Feet.	*Feet.*	
Sault Ste. Marie, Ontario, 6 miles north	1,015	434	Lawson.
Rexford, Mich. (probably highest)	[b] 930	349	Leverett.
Hessel	863	282	Goldthwait.
Mackinac Island [c]	809	228	Do.
Cross Village	746	165	Do.
Beaver Island	731	150	Do.
Harbor Springs	709	128	Do.
Norwood	674	93	Do.
Northport	658	77	Do.
North Manitou Island	648	67	Do.
Traverse City	619	38	Do.
Frankfort [d]	605(?)	24	Do.
Herring Lake	607	26	Do.
Arcadia	603	22	Do.
Muskegon	604(?)	23	Do.
Spring Lake	603	22	Do.
Holland	604	23	Do.

[a] In his early work the writer made many measurements of altitude on the Algonquin and Nipissing beaches by aneroid barometer and hand level, but these are now nearly all superseded by more accurate measurements by others.

[b] Railroad.

[c] On Mackinac Island the altitude given by Goldthwait (812 feet) is for a small, flat bench of gravel nearly 3 feet higher than the strong highest beach. The little bench is not the same kind of feature as the strong beach ridge. It gives no evidence of having been made by wave action and is therefore hardly to be put into the same category as the strong beach ridge. If it marks the level of the higher water body it must have been of local extent and without waves of any importance. If it is due to ice jamming during Lake Algonquin it is not a wave-made feature. In any event, it seems best not to take it as a point in the Algonquin plane in discussing the deformation of that plane. Goldthwait's measurement of the highest beach is about 809 feet and that value is used here.

[d] It is almost certain that the altitude given for Frankfort is not a record of the highest Algonquin. At Onekama on Portage Lake and at Bar Lake 4 miles north of Manistee the highest beach recorded is about 16 feet above the lake (597 feet altitude). This apparently is the Nipissing beach. The absence of the Algonquin beach seems to be due to the fact that during the time of that lake the embayments of Portage and Bar lakes were shut off from the main lake, as Portage and Muskegon lakes are to-day, so that the surf did not come into them from the large lake. Later, during the Nipissing Great Lakes, the obstruction was cut away and the waves entered and made a record of that lake level at the head of the embayments. At Frankfort the highest record is probably that of one of the lower members of the upper Algonquin group rather than of the highest.

On the west side of Lake Huron between Mackinac Island and Port Huron the highest Algonquin beach has altitudes as follows:

Altitudes of highest Algonquin beach on the west side of Lake Huron.

Locality.	Altitude above sea level.	Height above Lake Huron.	Authority.
	Feet.	*Feet.*	
Mackinac Island	809	228	Goldthwait.
Rogers	741	160	Gregory.
Crawford's quarry	741	160	Do.
Posen	741	160	Do.
Alpena	688	107	Do.
Ossineke	663	82	Do.
Harrisville	653	72	Do.
Greenbush [a]	642	61	Leverett.
Tawas	617	36	Gregory.
Omer	610	29	Do.
Worth	607	26	Do.
Kawkawlin [b]	610	29	Cooper.
Bayport [a]	607	26	Lane.
Sebewaing	605	24	Do.
Bridgeport	607(?)	26	Cooper.
Port Austin [a]	615	34	Gilbert.
Grindstone City [a]	615	34	Taylor.
Port Sanilac [a]	605	24	Do.
Port Huron [a]	606	25	Do.

[a] Determined by hand level. All are in situations very favorable for obtaining accurate results with this instrument, each of them involving only five or six short sights.

[b] The extra height of 3 or 4 feet here is in all probability due to wind-blown sand.

On the west side of Lake Michigan the altitude of the highest Algonquin beach has been determined as follows (see Pl. XXIV):

Altitudes of highest Algonquin beach on west side of Lake Michigan.

Locality.	Altitude above sea level.	Height above Lake Michigan.	Authority.
	Feet.	*Feet.*	
Burnt Bluff, Mich	723	141	Hobbs.
Deaths Door, Mich	660	79	Goldthwait.
Rowleys Bay, Mich	654	73	Do.
Oconto, Wis	620	39	Do.
Sturgeon Bay, Wis	621	40	Do.
Cormier, Wis	611	30	Do.
Algoma, Wis	610	29	Do.
Two Rivers, Wis	607	26	Do.
Evanston, Ill	605	24	Do.
Rogers Park, Ill	604	23	Do.

On the south side of Lake Superior a few measurements of the highest Algonquin, besides those at Sault Ste. Marie and Rexford, have been made by Mr. Leverett. Back of Houghton its altitude is 1,040 feet (aneroid), or about 440 feet above Lake Superior, and at Calumet it is 1,090 feet, or 490 feet above Lake Superior. In the Marquette quadrangle it lies near the 940-foot contour, and near Munising it is 953 feet, by wye level from Wetmore. On St. Joseph Island it is 934 feet as measured by Mr. Leverett by wye level.

In the western part of the Lake Superior basin—in fact, from the outer part of the Keweenaw Peninsula west—a number of beaches belonging to Lake Duluth and lower waters lie above those of Lake Algonquin, from which they have not yet been clearly differentiated. A further difficulty in the western part of the basin on the south side is the fact that a considerable part of the slope is covered with lake clay without pebbles or gravel and the beaches appear only as irregular and faintly cut benches.

As will be pointed out later, the hinge line of the Nipissing appears to pass across the west end of Lake Superior. If the Algonquin beach maintains the same relation to the Nipissing here as in the Lake Huron basin it would come to a horizontal attitude at the same line and would then descend nearly to present lake level at Duluth. But on the facts now available this seems improbable.

In southern Ontario the following instrumental measurements of the highest Algonquin beach have been made by Goldthwait and by W. A. Johnston (see Pl. XXV):

Altitudes of highest Algonquin beach in southern Ontario.

Locality.	Altitude above sea level.	Height above Lake Huron.	Authority.
	Feet.	*Feet.*	
Kirkfield	883	302	Goldthwait.
Beaverton	822	241	Do.
Holland Landing	752	171	Do.
Bradford	749	168	Johnston.
Beeton	729	148	Do.
Lefroy	775	194	Do.
Big Bay Point, back of	795	214	Do.
Barrie	785	204	Goldthwait.
Oro	811	230	Do.
Orillia	847	266	Do.
Ardtrea	883	302	Johnston.
Coldwater	852	271	Goldthwait.
Elmvale	829	248	Do.
Wyebridge	840	259	Do.
Penetang	855	274	Do.
Colwell	774	193	Do.
Mair Mills, 4 miles west of Collingwood	767	186	Do.
Clarksburg	769	188	Do.
Meaford	783	202	Do.
Owen Sound	748	167	Do.
Hogg	778	197	Do.
Wiarton	776	195	Do.
Port Elgin	710	129	Do.
Kincardine	666	85	Do.
Bayfield, 4 miles south	613	32	Do.
Grand Bend	607	26	Do.
Kettle Point	607	26	Do.
Sarnia	604	23	Do.

Goldthwait[1] gives a table of altitudes of the Algonquin beach in the area of horizontality. Most of these are included in the tables above. The averages for those in the Lake Michigan and Lake Huron basins taken separately show a difference of about a foot in the altitude of the beach in the two basins. One or two abnormally low measurements are included for Lake Michigan, and two abnormally high ones are included for Lake Huron. In a region in which many measurements agree in showing horizontality, measurements abnormally high or low should not be included in making averages. Perhaps it is not impossible that a slight hump or hollow may occur in an area where the beach is prevailingly horizontal, but present knowledge does not warrant such an assumption. No instance of such an occurrence has been proved. Altitudes of 603 feet for the Algonquin in the Michigan basin are a little below normal, and the altitudes of 610 by Cooper and 611 by Lane in the Lake Huron basin are abnormally high; and in both of the latter localities the beaches are known to be sandy and quite likely to be above normal height in consequence of wind action. If the abnormal measurements be omitted the altitude of the beach in the two basins becomes nearly the same.

The following measurements of the altitude of the Algonquin beach in Ontario were made by Spencer more than 25 years ago and, except where otherwise stated, were made with a spirit level. Some terraces which he gives in his table are omitted. The difference between these values and those obtained by Goldthwait are probably mainly due to slight differences of locality, for Spencer's descriptions of localities were seldom sufficiently detailed for exact identification.

Altitudes of highest Algonquin beach in Ontario.

Locality.	Altitude above sea level.	Height above Lake Huron.
	Feet.	*Feet.*
Grand Bend of Au Sable River	602	21
Southampton	714	133
Owen Sound	749	168
Clarksburg	773	192
Collingwood, 4 miles west	767	186
Colwell	752	171
Elmsvale	802	221
Wyebridge, east of	842	261
Orillia (barometer)	800±	219
Kirkfield	875	294

[1] Bull. Geol. Soc. America, vol. 21, No. 2, 1910, pp. 236-237.

At Colwell and Elmvale the difference is large, and seems to indicate either an error of measurement or a considerable difference of locality.

Some other altitudes in Ontario are of interest. It is not certain that any of them refer to the highest Algonquin, but it is thought some of them may. The one at North Bay is almost certainly that of a lower member of the upper Algonquin group.

Altitudes in Ontario.

Locality.	Altitude above sea level.	Authority.	Remarks.
	Feet.		
Bracebridge	1,007	Goldthwait	A light beach ridge.
Huntsville	1,007	....do	Notch of terrace.
Sundridge [a]	1,205	Taylor	Sandy beach ridge.
South River [a]	1,220	....do	Notch of terrace.
Trout Creek	1,221	Goldthwait	Gravelly beach ridge.
North Bay, 5 miles northeast	1,177	....do	Do.

[a] By aneroid barometer.

Coleman has reported deposits which he regards as beaches at high levels in the region north of the Great Lakes. The highest is 30 miles northwest of Michipicoten Harbor and 70 miles west of Missanaibi. It is described as "a very distinct terrace, of coarse but well-rounded gravel and stones, 1,445 feet above the sea."[1] Near the same locality is another sandy terrace at 1,380 feet. Similar deposits are at Gondreau Lake, 20 miles southwest of Missanaibi, altitude near 1,500 feet; near Meteor Lake, 1,420 feet; near Monabasing Lake, 1,335 and 1,316 feet; near Geneva, north of Cartier, 1,400 feet; and 12 miles northwest of Wahnapitae Lake, 1,047 feet.

It may be doubted whether any of these deposits are true beaches due to wave action in large bodies of water. The descriptions seems to reveal forms which were much more probably formed by glaciofluvial action or were associated with relatively small and local bodies of ponded waters. Nevertheless, some of them may be beaches and may belong to the Algonquin group. It is at least a very singular coincidence that if the plane of the highest Algonquin beach, from Hessel, Mich., to Root River, north of Sault Ste. Marie, be produced northward, it passes the locality at Gondreau Lake at about 1,470 feet.

In the writer's reconnaissance on the north coast of Lake Superior and in Lawson's more accurate work the highest Algonquin was not certainly identified at any place.

BATTLEFIELD GROUP OF ALGONQUIN BEACHES.

DISTRIBUTION.

Mackinac and adjacent islands.—On Mackinac Island next below the upper Algonquin group the surface for about 20 feet is bare or very thinly covered rock, or is a stony bowlder pavement. This interval is the surf-wasted zone below the lowest strong strand of the upper Algonquin group. For 20 feet farther down there are one or two very weak beaches, below which, in the next 20 feet of descent, there are two or three beaches, the upper one of which is generally strong and has some remarkable peculiarities. This is the Battlefield beach. It is called by this name because it was first observed and is most characteristically developed on the battlefield of August 4, 1814, on northern Mackinac Island. The locality is now a part of the golf links. The beach forms a strong, beautifully shaped, and even-crested crescentic ridge trending west from some rough knolls of limestone.

Though in places it contains much sand and fine gravel, this beach in nearly every locality where it has been identified is characterized by unusual coarseness of composition and steep front and back slopes. In some places it looks as though it was formed partly from stones and bowlders shoved up by the ice into something like an ice rampart. Where cut by the road to British Landing it has an uncommonly coarse composition, being made up largely of stones and small

[1] Coleman, A. P., Marine and fresh-water beaches of Ontario: Bull. Geol. Soc. America, vol. 12, 1900, pp. 138-143.

bowlders 5 to 10 inches in diameter. Toward the west its texture is finer, but includes considerable coarse material. In places it stands 6 to 10 feet above the ground back of it. (See Pl. XXVI, *A*.)

At Mackinac Island and St. Ignace, and wherever it has been recognized farther south, this beach seems to lie on a stony, bowldery pavement like that commonly found below strong beaches. Farther south, in fact, it stands on the bowlder pavement of the lowest strand of the upper Algonquin group, but at Mackinac Island it is 40 feet below the lowest of that group. The bowldery belt on which it occurs is in many places wide and flat and very stony, so that the material available for building the ridge was largely coarse, and the situation favored the building of ramparts.

The beach is also peculiar in that, although remarkable for its strength in some localities, it is very weak in other places that seem not unfavorable for its formation. So far as observed, it does not split nor show double or multiple forms. In most places, however, it is accompanied by one or two lighter ridges, which seem to be more closely related to it than to the groups above or below. These may have split off at points farther south. This group of ridges is therefore called the Battlefield group.

From the battlefield on Mackinac Island the beach runs westward across the island and is cut off abruptly at the edge of the great cliff which rises 85 feet from the Nipissing bench below. Another short fragment of the Battlefield beach occurs a few rods northeast of the Grand Hotel as a barrier between two knolls. What seems to be the lowest strand of the Battlefield group appears a little east of the Grand Hotel as a low, gravelly barrier ridge with beautifully crescentic form. It occurs also in fine form about a mile west of St. Ignace as a heavy gravelly ridge running northwest and turning back to the east in a sharply hooked spit.

Beaver Island.—On Beaver Island the Battlefield beach is particularly well formed in the western-middle part of the island, where it faces northwest. Its peculiarities of composition and form on Mackinac Island are here even more strongly displayed, suggesting ramparts.

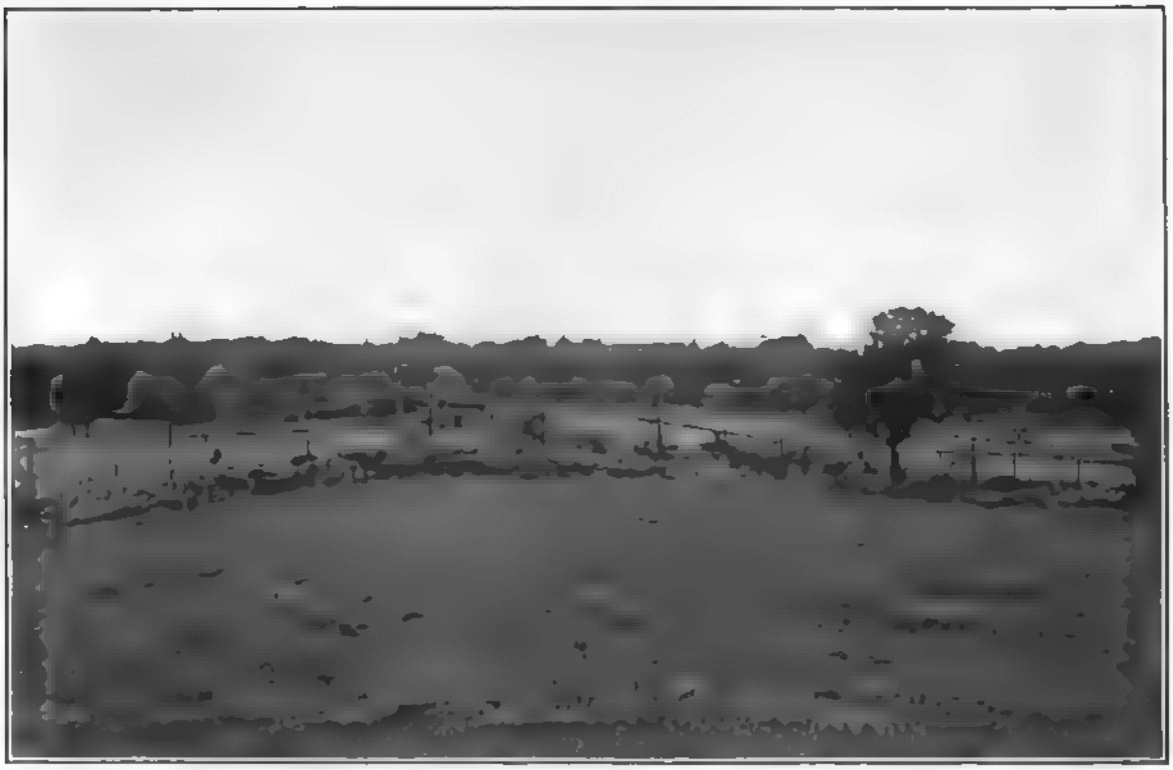
West of Cheboygan.—Except in one locality, the Battlefield beach has not been followed continuously for any considerable distance, but it has been identified satisfactorily at a number of points on the mainland south of the Straits of Mackinac. It was found about 3 miles south of Mackinaw City and was observed in fairly strong development at several places between there and Cheboygan. It was followed almost continuously from south of Mackinaw City southwestward nearly to Cross Village. (See Pl. XXVI, *B*.) It passes about half a mile south of French Farm Lake and wraps around the north side of a morainic knoll 2 miles east of O'Neal Lake, forming a fine crescentic ridge open to the north for 1½ miles to the west. Thence it continues west and southwest around the headland south of Sucker Creek and turns back in a nearly circular loop around Wycamp Lake. It appears again back of Cross Village and extends 2 miles southwest. In this stretch it is generally a well-formed ridge, with the usual stony gravelly composition and bowldery foreslope.

West of Bear Creek in Petoskey, at Burgess, Charlevoix, and Norwood, this beach was recognized. Locally, as near Burgess, it is strong, but in some places it is ill defined. At Northport and Leland a beach ridge that apparently corresponds to it was found, but the distances between points of observation were rather large, and the vertical interval above the Nipissing was so contracted that its identity does not seem certain.

East of Cheboygan.—Between Cheboygan and Alpena most of the writer's observations were made a number of years ago, mainly before particular attention was paid to the weaker beaches below the upper Algonquin group, and although he found some rather weak beach ridges apparently corresponding to the Battlefield beach at several places he did not particularly note their characteristics and relations. At several places Gregory reports a beach or group of beaches which appear to have the place and relations of the Battlefield group, but their identity was not fully determined.

Ontario.—In Ontario, at several places along the south side of Georgian Bay, Goldthwait and the writer found a shore line which appeared to correspond to this beach, but it seemed generally not so well developed as in Michigan and less characteristic. Mr. Leverett found this beach and its associated lighter beaches at several places on the northern peninsula and in Ontario

A. REAR VIEW.



B. VIEW WEST ALONG CREST OF BEACH.

BATTLEFIELD BEACH, MACKINAC ISLAND, MICH.

north of Sault Ste. Marie and on St. Josephs Island. It seems certain also that some of Lawson's numerous series on the north side of Lake Superior belong to this group.

ALTITUDE.

On Mackinac Island the strongest, most characteristic ridge of the Battlefield group—the one to which the name was originally applied—lies in a plane about 90 feet below the highest and 40 feet below the lowest of the upper Algonquin group. The altitudes of this beach as determined by Goldthwait's spirit leveling are given in the following table. The measurement at Sault Ste. Marie, Ontario, is by Mr. Leverett.

Altitudes of Battlefield beaches on Mackinac Island and in vicinity.

Locality.	Altitude above sea level (in feet).	Altitude below highest Algonquin (in feet).	Altitude of other weaker members of group (in feet).
Sault Ste. Marie, Ontario	790	139	
Hessel, nearly 3 miles north	741(?)	121(?)	
Mackinac Island, battlefield	719	91	Higher, 726, 729, 732, and 734.
Mackinac Island, northeast of Grand Hotel	715	94	Lower, 703.
Mackinac Island, Benhams road 1 mile south of British Landing	715	94	Higher, 718; lower, 703.
St. Ignace, 1 mile west of courthouse	710	....	
Mackinaw City, 3 miles south[a]	694	73(?)	Lower, 693, 691.
Cross Village, three-fourths of a mile east	689	56	Higher, 704, 705.
Beaver Island, west-central part	682	48	Higher, 690.
Petoskey	666(?)	31	Higher, 668.
Burgess	664	33	Higher, 676.
Charlevoix	661(?)	24	Lower, 652.
Norwood	651(?)	22	
Lake Michigan, July and August, 1907	581.6	....	

[a] The highest beach on the line south from Mackinaw City to Carp Lake has an altitude of 757 feet near north side of Carp Lake. But it is doubtful whether this is the highest Algonquin, for by comparison with other localities near by it seems about 10 feet too low. There is no higher ground near this place.

Gregory's report on his spirit leveling is not yet published, so that identification of the principal Battlefield beach in places is as yet in some doubt, but it seems to be represented by the following beaches: [1]

Location and altitudes of supposed Battlefield beaches.

Locality.	Altitude above sea level.	Altitude below highest Algonquin.
	Feet.	*Feet.*
Rogers	690	50
Crawford's quarry	690	48
Posen	690±(?)	48±(?)
Alpena, north	690	([a])
Alpena, west	651	37
Ossineke	641	22

[a] Highest Algonquin not reported.

The Battlefield group north of Sault Ste. Marie, Ontario, was found by Mr. Leverett to cover a vertical interval of about 150 feet. Its upper and lower limits, however, have not been determined with entire certainty.

One of the most important results of Goldthwait's survey was the determination of the southward convergence of the Battlefield beach with those above and below. It had been supposed by some geologists, including the writer, that the Battlefield and Fort Brady beaches were each due to a drop in lake level resulting from the opening of an outlet eastward to the Ottawa Valley. This would place these beaches in planes passing southward below the Port Huron and Chicago outlets and would mean that they pass southward below the Nipissing beach, which is of later date and connects with the Port Huron outlet. Goldthwait's measurements, however, show that the Battlefield beach converges with the highest Algonquin beach toward the south and less rapidly with the lower beach of the upper Algonquin group and with the Fort Brady and Nipissing

[1] Gregory, W. M., personal communication.

beaches below. Thus it is not parallel to any of the other beaches, as it would be if the lake had been lowered suddenly by the opening of a new outlet.

Although Goldthwait's work does not carry the Battlefield and Fort Brady beaches southward to an absolute union with any of the Algonquin beaches, it carries them so far in that direction that it leaves almost no doubt that they do in fact converge with the lowest member of the upper group. This result seems to preclude the idea of outlets to the Ottawa Valley, except from the last, lowest level of the Fort Brady beaches. In order that the Nipissing Great Lakes could come into existence with full discharge eastward to the Ottawa Valley, there had to be at least a slight drop from the lowest level that could discharge at Port Huron. But that drop was apparently from the lowest Fort Brady to the original Nipissing which is now submerged in all the region south of the isobase of North Bay. There is perhaps some doubt as yet as to whether the lowest beach or two now classed as Fort Brady may in fact belong to this transition to the Nipissing stage. Present facts seem against this view, but they are not conclusive.

The facts seem to show that all but the very last and relatively small increment of the uplift that began during Lake Algonquin turned on a hinge line without the intervention of a drop of lake level by the opening of a lower outlet. Hence, the whole vertical interval from the highest Algonquin down apparently to the lowest Fort Brady measures the vertical uplift during Lake Algonquin.

FORT BRADY GROUP OF ALGONQUIN BEACHES.

DISTRIBUTION.

At Fort Brady, in the southwest part of Sault Ste. Marie, Mr. Leverett found a cut bench and cliff distinctly above the Nipissing and below anything that seemed likely to belong to the Battlefield. He called it the Fort Brady beach. At other places this interval between the Battlefield and Nipissing beaches was found to be occupied by a number of closely set, rather light gravel ridges which seem to constitute a group by themselves. Where typically developed in the north several such beaches, separated by rather small vertical intervals generally less than 10 feet, occupy an interval above the much stronger Nipissing beach and below the Battlefield group, which seems to be distinctly set apart by a barren interval wider than usual.

These beaches are persistent in all the northern region, but like the Battlefield beach, they have nowhere been traced continuously for any considerable distance.

At Mackinac Island they are not very well developed. Just east of the Grand Hotel they occur as a group of very faint, short bars tying knolls of limestone. Four or five short ridges belonging to this group lie in the woods above the Nipissing beach back of British Landing in the northern part of the island and are considerably stronger than those near the Grand Hotel.

At St. Ignace five fairly strong gravelly beach ridges which seem to belong to this group are displayed in best development in the south part of the town. The highest two are strong and beautifully formed ridges, and all are stronger than at any other place observed south of Sault Ste. Marie.

On the road north of Hessel two wave-cut benches between the Nipissing and the Battlefield beaches probably belong to the Fort Brady group. Between Mackinaw City and Carp Lake one strong, gravelly ridge and one faint one represent this group. Two or three ridges of the same set were observed at several points between Mackinaw City and Cheboygan, and two or three were observed between Mackinaw City and Cross Village.

At nearly all of the many places where the Nipissing shore line is developed as a heavily cut terrace with a high lake cliff behind it the Fort Brady beaches have been destroyed. This is the case on the east and west sides of Mackinac Island, at Cross Village, at Harbor Springs, and in the whole interval between these last two. At Petoskey two gravelly ridges appear to stand in the place of this group, but at Burgess they are cut away.

The fullest development of Fort Brady beaches found is on Beaver Island. Seven or eight ridges in the northeast part of this island seem to belong to the Fort Brady. The highest, perhaps, belongs to the Battlefield group, leaving seven ridges, four of them strong and three rather faintly developed. At Charlevoix there are two or three. At Norwood one ridge and

possibly two seem to belong to the Fort Brady. Farther south the vertical interval between the lower member of the upper Algonquin group above and the Nipissing below is so narrowed that in the absence of strong individual characteristics it is impossible to distinguish with certainty between the Battlefield and Fort Brady groups. Both groups are crowded into narrower space and are represented by fewer ridges than farther north.

Beaches having moderate strength and now recognized as belonging in all probability to the Fort Brady group were seen by the writer a number of years ago near Rogers and farther south. In Gregory's summary of his leveling operations beaches that probably belong to the Fort Brady group were observed as far south as Alpena, but their identification is not yet certain.

In Ontario the Fort Brady group of beaches is fairly well developed at some localities, especially along the north side of the Penetang Peninsula, but they are generally not strong. They were found also at some places along the south side of Georgian Bay, but are not so well displayed there as farther north.

At North Bay, Ontario, where some of the beaches are well developed a mile north of the town on a terrace overlooking the head of the North Bay outlet channel, the upper and lower limits of the group have not been definitely determined, although the lower limit appears to be at a beach about 50 feet above the Nipissing. At this place four beaches, including the lowest and covering a vertical interval of 31 feet, appear to belong to the Fort Brady group. In all probability there are higher ones and perhaps lower ones, although several fairly favorable localities near North Bay did not appear to show them.

Mr. Leverett reports this group of beaches from several places on the northern peninsula. In 1893 the writer found them faintly developed at several places on the south side of Lake Superior, and subsequently Mr. Leverett found them at other localities. The writer visited several of Lawson's north-shore localities in 1895 and at most of them saw light beaches above the Nipissing which it now seems evident belong to the Fort Brady group.

ALTITUDE.

In the Fort Brady group of beaches no single beach has strength or individual characteristics that make it possible to distinguish it from other members at different localities, and it is not possible to trace the variations of the group in altitude with accuracy. The altitudes given below, compared with the altitude of the Nipissing beach at the same places, show the general relations.

Altitudes of the Fort Brady beaches.

Locality.	Altitude above sea level (in feet).	Altitude of lowest beach above Nipissing (in feet)	Altitude of Nipissing beach (in feet).	Altitude of highest beach above Nipissing (in feet).
North Bay, Ontario	748, 763, 776, 779 (lowest may be cut away)	50	698	77
Sault Ste. Marie, Mich.	699 (higher and lower cut away)	48	651	....
Mackinac Island, north end	656, 659, 668, 672	15	641	31
Mackinac Island, Benhams road	669, 691 (lowest cut away)	28	641	50
Mackinac Island, south end	639, 653, 661, 681	5	634	47
St. Ignace, west of town	654, 662, 668, 677	26	628	50
St. Ignace, south part	645, 652, 655, 662, 678	17	628	49
Mackinaw City	653, 656	25	628	28
Beaver Island	634, 642, 645, 649, 652, 655, 659	11	623	36
Petoskey	649, 654 (lowest cut away)	36	613	41
Norwood	641 (lowest cut away)	34	607	34

At the south end of Mackinac Island a faint gravel ridge which rises only 5 feet above the Nipissing beach a few yards away may be merely a storm ridge of the Nipissing. Aside from this, both the upper and the lower members, where the latter are not cut away, appear to be somewhat higher in the north than in the south, but it is perhaps an open question whether some of the Fort Brady beaches may not pass southward under the Nipissing beach. South of Charlevoix and Alpena there are in many places one to three beaches between the Nipissing and what seems clearly to be the lowest ridge of the upper Algonquin group, but it has not been

found possible so far to tell whether these are all Battlefield or Fort Brady, or are divided between the two. In the stretch between Mackinac Island and St. Ignace on the north and Cross Village on the south, although accurate measurements are not available for the latter place, the impression that the Fort Brady beaches lie in planes sensibly parallel with the Nipissing plane is strong enough to lead to the provisional conclusion that the Fort Brady beaches, or at least the upper ones, do not pass down under the Nipissing plane. This would mean that the opening of the eastward outlet for Lake Algonquin to the Ottawa Valley occurred at the end or very near the end of the Fort Brady substage of the lake.

The convergence of the planes of the lower members of the upper Algonquin group suggests that during that part of the uplift a hinge line may have existed in the vicinity of Traverse City. Similar suggestions of a subsidiary hinge line occur near Tawas City and on the east side of Lake Huron. This line runs parallel with the main Algonquin hinge line and about 25 miles north of it. The uplift related to this line appears to have taken place sometime after the formation of the highest Algonquin beach but before the Nipissing beach, for the latter appears not to have been affected by it. The data in hand at present, however, seem insufficient to settle the questions suggested. (See fig. 8.)

OTTAWA OR CLOSING TRANSITIONAL STAGE.

It seems certain that an outlet for Lake Algonquin to the Ottawa Valley opened before the beginning of the Nipissing Great Lakes and the full eastward discharge over the col at North Bay, but the facts at present available are not decisive. The opening of a lower outlet could hardly have resulted from elevation alone. Something must have given way or have been withdrawn to afford a lower passage.

This early drainage to the Ottawa Valley may have prevailed during all or a part of the formation of the Fort Brady beaches or it may have begun with the abandonment of the last. In any case it marked the last stage of Lake Algonquin and the transition to the Nipissing Great Lakes.

GLACIAL BARRIERS OF LAKE ALGONQUIN.

Although from first to last Lake Algonquin endured for a relatively long time, certainly much longer than did any of the Huron-Erie lakes that preceded it, the precise position of its ice barriers at any of its stages is not known from observation.

The position of the barrier for Early Lake Algonquin, however, seems fairly well determined, only slight uncertainty remaining as to the correlation of the moraines on the two sides of Lake Huron.

In Michigan the main moraine of the Port Huron morainic system turns northwest on the north side of Au Sable River, about 20 miles west of Greenbush in Alcona County. In Bay and Tuscola counties the next later moraine is the Bay City. This passes 5 or 6 miles northwest of Tawas, but it has not been surely identified in the jumbled and broken area northwest of Harrisville. Still, from its lower altitude west of Tawas, it seems certain that it lies lower down on the slope north of Au Sable River. The Tawas moraine passes close along the lake shore at Alabaster and Tawas and seems to be continued in the prominent ridge that passes close west of Greenbush and Harrisville. From Black River it is continued in the chain of knolls that run northwest and along the base of which lies the Algonquin beach. South and west of Rogers the Algonquin beach runs along the inner base of a high morainic mass which rises 40 to 100 feet above it. From the vicinity of Rogers the divide between the drainage basins of Thunder Bay River on the southeast and the Ocqueoc and Black rivers on the northwest runs southwest with no passage across it as low as the Algonquin beach. Hence, the waters of the Lake Huron basin in the time of Early Lake Algonquin, or even after this stage, could not have found open connection with the waters of the Lake Michigan basin until the ice front had withdrawn somewhat from this high morainic mass.

On the Canadian side the continuation of the main moraine of the Port Huron system turns northeast 7 or 8 miles north-northwest of Clinton and the next moraine takes a parallel course northeast from Goderich. The latter moraine appears to be the precise equivalent of the Bay City moraine in Michigan. Following this, five light moraines set close together run northeast from the brow of the Algonquin cliff between Clark and Douglas points, the first one terminating a little south of Clark Point. These are slender ridges, and at present are known only as fragments near the shore. Their courses inland have not yet been worked out, but the characters mentioned suggest that they are deployed ridges of a single moraine, and their places in the series suggest that taken together they may be equivalents of the Tawas moraine in Michigan. Next comes a strong moraine that begins near the shore about 8 miles south of

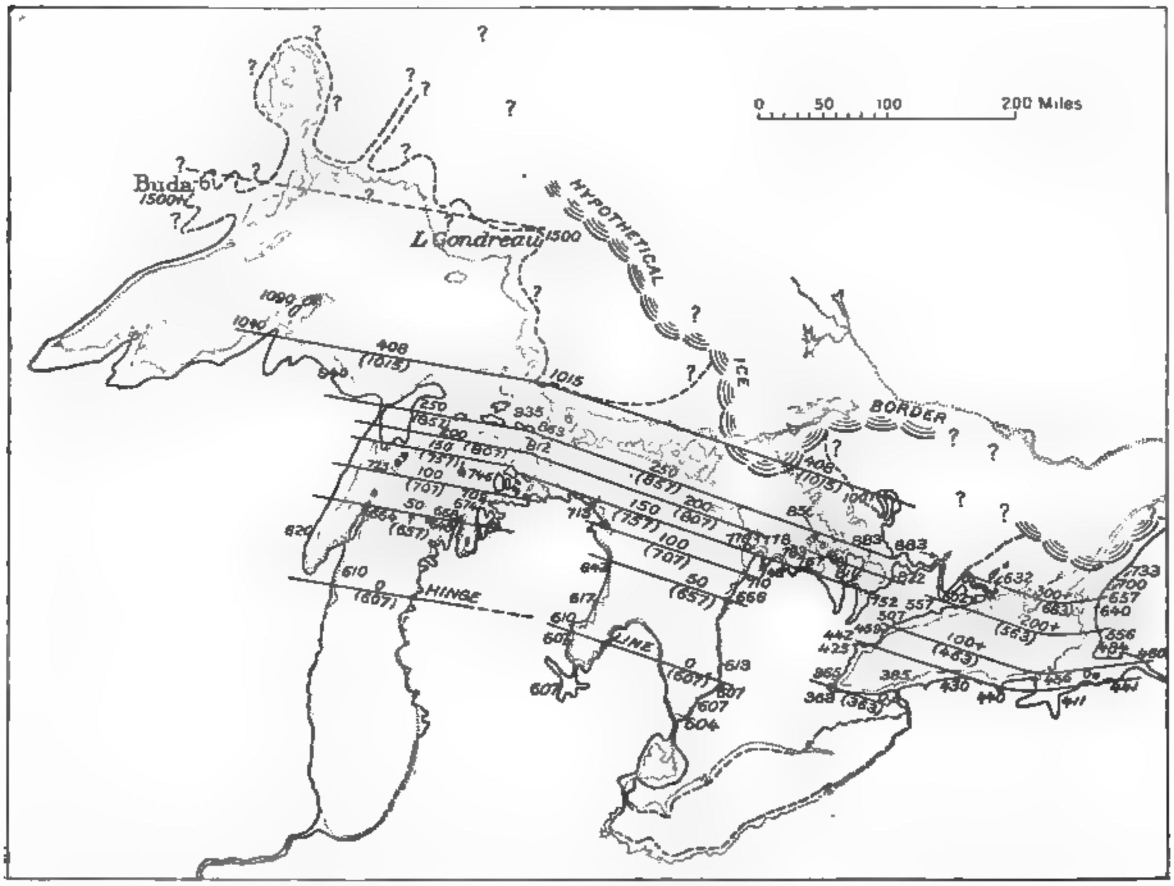


FIGURE 8.—Map showing isobases of Lake Algonquin at its highest stage and isobases of Lake Iroquois as represented by Goldthwait. The numbers above the isobases are altitudes above the horizontal or unaffected part of the beach south of the hinge line; the numbers in parentheses below the isobases are altitudes above sea level.

Port Elgin and runs northeast to Hepworth, where it turns back to the southeast around the head of the Owen Sound embayment. It passes close east of Port Elgin and may be called the Port Elgin moraine. If the five light ridges south of this moraine are equivalents of the Tawas moraine, then this one may be regarded, at least tentatively, as the equivalent of the Cheboygan moraine in Michigan. From the relations of several morainic fragments observed by the writer, it seems probable that at this halt the ice front extended eastward along the base of the high escarpment between Owen Sound and Collingwood and only a little above the Algonquin beach, and that after swinging east and north across the Nottawasaga and Severn valleys, it made a deep northward reentrant toward the highlands of Algonquin Park, returning south and southwest along the northern margin of the lobe that projected into the basin of Lake Ontario.

In the bed of Lake Huron a well-marked escarpment, now submerged and shown on the charts by the 50-fathom line, runs northwest from near Kincardine. North and east of this line lies the deep trough of Lake Huron; south and west of it the lake is much shallower. The general movement of the ice was southwestward across Georgian Bay and the deep trough. The form of the lobation which the ice assumed under the influence of the deep trough and the surrounding lands seems to find normal expression in the moraines described; that is to say, the moraines are disposed about as would be expected under the laws governing the movement of the ice over such a surface. The Port Elgin moraine rises only a little above the Algonquin beach east of Port Elgin and Southampton, and in this respect stands in about the same relation to the Algonquin beach as the Cheboygan moraine near Rogers, in Michigan.

With the ice front resting on this moraine, the waters in the south part of the Lake Huron basin would necessarily discharge southward at Port Huron and the lake in that relation would answer perfectly to the description Early Lake Algonquin. At the next step of ice retreat, however, passages were opened possibly both to the west and east, and the discharge may have passed partly, though for only a very brief time, to Chicago; almost immediately, however, the whole discharge passed to Kirkfield.

At this stage the ice barrier rested largely in the lakes and rested on land only in Canadian territory. If the recession of the ice front after as before the formation of the Port Elgin moraine was marked by a series of halts, the moraines formed must be found mainly in the country east and north of Georgian Bay and north of the North Channel of Lake Huron. The writer has explored along certain lines in those wild, rough regions and has observed six or seven moraines that may be members of such a series, but they are all short fragments and their connections and relations are not known. Ice tongues pushed southward in two or three deep valleys that enter the Ottawa Valley from the north, impinging heavily against the high south side and forming effectual dams for the waters west of them.[1] These mark, it is believed, the last position in which the ice sheet acted as a retaining barrier for the waters of Lake Algonquin. But in the wide stretch of country between these tongues and the Port Elgin moraine there is room for a number of moraines. If rhythmical halts or oscillations of the ice front occurred in this interval, as they did farther south, they will ultimately afford a good basis for the measurement of the relative duration of Lake Algonquin and of the time and rate of the uplifting movements which deformed its shores.

CORRELATIVES OF LAKE ALGONQUIN.

COMPLEXITY OF RELATIONS.

Lake Algonquin endured for a relatively long time, during the latter part of which the most profound earth movements that have affected the Great Lakes region since the time of the ice sheet took place. For this reason it might be expected that the correlatives of Lake Algonquin, especially in the basins of Lakes Erie and Ontario, would have somewhat complex histories, as indeed they have. The chief correlatives of Lake Algonquin were Lake Erie and glacial Lake Iroquois. Other correlatives existed in the basins of Lake St. Clair and Rouge River.

LAKE ST. CLAIR.

During the time of Early Lake Algonquin the waters in the basin of Lake St. Clair stood 8 or 10 feet lower than in the basin of Lake Huron. Along its western side a well-defined, though not very strong, old shore line, which may be called the first St. Clair beach, is 595 feet above sea level at all points where it has been measured. The altitude of the Algonquin beach near Port Huron is 605 to 607 feet, and therefore, in strict sense, the first St. Clair beach is not the early Algonquin beach but a correlative of that beach, made at a lower level in a basin connected with Early Lake Algonquin by a river that descended 8 or 10 feet.

[1] Taylor, F. B., Notes on the Quaternary geology of the Mattawa and Ottawa valleys: Am. Geologist, vol. 18, 1896, pp. 108-120.

The first St. Clair beach is scarcely traceable along the river front in Detroit, but it crosses Jefferson Avenue about a quarter of a mile west of the waterworks as a faint wave-cut bench with no noticeable cliff and then turns away inland. It runs thence a little east of north to Mount Clemens and thence northeast for about 10 miles and fades into an ill-defined sandy belt on the clay plain north of Anchor Bay. It lies 2 to 4 miles back from the present shore of the lake for its whole course except 2 or 3 miles along the bay north of Mount Clemens, where it is not over 1 mile back. In this part it is stronger than common and has a well-defined lake cliff at its back 3 to 7 feet high. An island which at the time of this beach reached northeast for about 2 miles from Grosse Pointe is about half a mile wide and, in a small area on the Moran road at its western edge, rises to 620 feet above sea level and is capped with gravel which, from its altitude, appears to belong to the Lundy beach. The first St. Clair beach runs through the village, generally an eighth to a quarter of a mile from the shore, in the form of a low beach ridge of gravel. A gravel spit rising a little above the general level of the beach runs 70 or 80 rods southwest from the southwest end.

Grosse Pointe Island was separated from the mainland to the west by a trough the lower part of which is half a mile wide and swampy. This runs through from Milk River at the north to the flats of Fox Creek a mile southwest of the village and is now only 5 or 6 feet above the lake. It is floored with several feet of lake clay and was therefore originally somewhat deeper.

The island is distinctly morainic and the shore all along its front is paved with bowlders. Three miles to the south the lighthouse at Windmill Point stands on a small isolated fragment of bowldery till, probably part of the same moraine.

On the south shore of the lake 25 miles east of Windsor, Ontario, the land projects into the lake in a wide blunt cape called Stony Point. Its shore is bowldery and suggests morainic ground, but the flat land of that vicinity does not indicate its course and no detailed studies have yet been made in that region.

On the Canadian side the first St. Clair beach has not been traced. The country surface is very low and flat to the south and east, indicating a much wider interval between the old beach and the present shore. The altitude given on the Canadian official topographic maps indicate a line passing east from Walkerville 2 to 3 miles back from the shore, the distance increasing eastward. It passes a mile north of Comer and 2 miles south of Tilbury. Five miles east of Tilbury this line is slightly nearer to Lake Erie than to Lake St. Clair. Along this line nearly all the streams show jogs indicating some diverting influence, such as would be exerted by a beach. Thence the probable course, as indicated by the altitudes, passes a few miles west of Chatham and a little east of Wallaceburg and to St. Clair River a few miles south of Courtright. On such flat ground the beach would be likely to be merely a low belt of fine sand. Several fragments of this sort have been observed west of Chatham and toward Wallaceburg but have not been traced connectedly.

The basin of Lake St. Clair is simply an intermorainic trough or original depression in the drift lying between the main moraine of the Port Huron system on the north and another moraine which passes through Detroit and Windsor and along the north side of Lake Erie from near Leamington. It is probably accidental that the lowest point on the Detroit moraine was at Detroit instead of at some point farther east, as near Tilbury, where it would be more centrally located with reference to the axis of the Lake Huron glacial lobe.

The greatest depth in Lake St. Clair is 22 feet. Its surface at present has an altitude of 575 feet above sea level. At the time of the highest Algonquin beach (Early Lake Algonquin), its altitude was 595 feet, or 20 feet above its present level, and at the time of the Nipissing beach its altitude was 587 feet, or 12 feet above its present level. Lake St. Clair came into existence at the same time as Early Lake Algonquin.

LAKE ROUGE.

With the beginning of Lake St. Clair and the fall of the waters in the Lake Erie basin Lake Rouge was formed between Detroit and the barrier at Limekiln crossing by an expansion of Detroit River. The lake spread some distance over low ground on the Canadian side, but its larger part was over the flats of Rouge River west and southwest of Detroit.

Rouge Lake was small, but during the time of Lake Algonquin its waves formed a faint beach which belongs to it alone and does not lie in the plane of any other beach. This beach appears as a distinct wave-cut notch on the gently sloping clay plain west and southwest of Wyandotte and as a distinct low beach ridge of gravel on the north and northeast sides of Grosse Isle, especially near the lighthouse and for a mile or two to the south. Its altitude is 589 feet.

At the lower level of the Nipissing waters Lake Rouge was so reduced in area that it was almost obliterated and probably had no waves of any importance. No distinctly wave-made features were found for this level, but low, sandy ridges at Wyandotte and Ecorse, 6 or 8 feet above Detroit River, probably mark its position.

LAKE ERIE.

SEPARATION FROM GLACIAL LAKES.

Until its separation from Early Lake Algonquin Lake Erie was a part of the Huron-Erie glacial waters described above, Lake Lundy being the last stage. Immediately following its separation from Early Lake Algonquin Lake Erie was also separated from the glacial waters of the Lake Ontario basin, and ceased to be a glacial lake. After this separation the only changes which affected it were slight uplifts of the land and large changes of volume in the water which it received and discharged. The largest uplift which affected the Lake Erie basin occurred before the lake became independent—during the time of Lake Lundy. The span of Lake Erie's existence as an independent lake is the precise time equivalent of the duration of Niagara River and the Falls.

SEQUENCE OF STAGES DURING LAKE ALGONQUIN.

During Early Lake Algonquin Lake Erie stood at a somewhat lower level than now, and received a large volume of inflow through Detroit River, which of course gave it a large outflow at Buffalo. The Buffalo outlet, however, was on a rock sill with only very slight fall, and it remained firm and the lake was held steadily at one level. This was Lake Erie's first high stage, and its beach in the western part of its basin was probably 20 to 30 feet lower than the present surface.

Soon, however, an outlet was opened at Kirkfield, Ontario, and this took the whole discharge of the upper three lakes away from Lake Erie, causing a reduction of outflow at Buffalo amounting to about 85 per cent and lowering the level of Lake Erie 10 to 15 feet. This first low stage of Lake Erie lasted throughout the Kirkfield stage of Lake Algonquin. It therefore occurred before the Algonquin uplift, and its beach was probably 10 or 12 feet lower than in the preceding (Early Lake Algonquin) high stage.

The first low stage of Lake Erie was ended by the uplift which raised Kirkfield, closing the outlet there and sending the discharge of the upper lakes back to Port Huron and Chicago. The uplift affected the outlet of Lake Erie at Buffalo much less than it did that at Kirkfield, raising the former probably only 20 or 30 feet and backing the water up this much in the west end of the lake. The closing of the Kirkfield outlet gave Lake Erie a large volume of discharge and a high stage on its shores, and this condition lasted until the retreating ice opened a lower outlet in the Ottawa Valley and Lake Algonquin came to an end.

EFFECTS OF ALGONQUIN UPLIFT.

In the Lake Erie basin the area of horizontality for the Whittlesey beach extends about to Ashtabula, Ohio, and for the Warren beach about to the Ohio-Pennsylvania line. The hinge line for the Algonquin water plane, if produced as a straight line from the southern part of Lake

Huron, passes about halfway between Dunkirk and Silver Creek, N. Y., and about 30 miles southwest of Buffalo. On the "thumb" in Michigan the Warren beach at this line has an altitude of about 755 feet, or about 75 feet above its horizontal, undisturbed part. Two miles northeast of Sheridan, N. Y., on the same line produced, the Warren beach has an altitude of about 760 feet, or about 80 feet above its horizontal part; that is to say, it is uplifted about the same amount as at the Algonquin hinge on the "thumb." It is not known, however, that the Algonquin hinge line touches this point in New York; and on the other hand, it is not known that all the uplift at this place is of pre-Algonquin age. If the Algonquin hinge line produced to the southeast bends out of a straight course before reaching Sheridan, it is more likely to bend to the north, in harmony with the isobases of the Iroquois water plane, than to the south.[1] This would indicate a slightly larger pre-Algonquin uplift along the hinge line in New York than on the "thumb," but the difference is probably small. Fairchild finds the uplift farther northeast to be about 2 feet to the mile. This, if continued to the 80 feet of uplift near Sheridan, would make 140 feet in all at Buffalo. This is only approximate, but it is the best estimate now available for the amount of uplift at Buffalo before the beginning of Lake Algonquin. It would give the Warren beach at Buffalo an altitude of about 820 feet. At Alden, 20 miles east of Buffalo, however, it is 845 to 850 feet, the direction of greatest rise being only a few degrees east of north.

Facts in two areas bear indirectly on the amount of uplift at Buffalo during and after the existence of Lake Algonquin. On the west side of Saginaw Bay the Algonquin beach rises about 18 feet in 30 miles up the tilted water plane from the hinge line. This represents the combined Algonquin and post-Algonquin uplifts. The rate is slightly less for the same distance north from the hinge line on the two sides of Lake Michigan, and it is slightly greater on the east side of Lake Huron, the rate apparently increasing gradually eastward. Data derived from the Iroquois beach in the basin of Lake Ontario will probably be helpful in the future, but are not now available. If the assumed position of the hinge line in New York is not wide of the truth, and if the rate of rise is about the same or slightly greater than on Saginaw Bay, it may be said that at the beginning of the Algonquin uplift the outlet at Buffalo was somewhere between 15 and 25 feet lower than now, and that the uplift caused this much drowning in the western part of Lake Erie. This seems to show that the greater part of the deformation of the basin of Lake Erie, say 110 or 120 feet of uplift at Buffalo, was before the time of Lake Algonquin, and before the independent stage of Lake Erie. Hence, only a little additional uplift during and after the existence of Lake Algonquin was required to bring the waters nearly to the present level of Lake Erie and very nearly to the plane of the drowned shore described by Moseley. (See p. 462.) By the best estimate now available this amounted to 20 or 30 feet.

FORT ERIE BEACH.

In 1907 the writer found a strong old shore line, the Fort Erie beach, extending westward along the Lake Erie shore from Fort Erie, Ontario. It is a gravel ridge in Fort Erie and is strong at intervals as far west as Lowbanks, beyond which it has not been traced. It is nearly horizontal, standing 14 to 15 feet above the lake in Fort Erie and only 4 or 5 feet lower at Lowbanks, 28 miles to the west. This beach is distinctly old, is considerably weathered, and is generally preserved only on rocky parts of the shore, where it could not be undercut by later wave action at lower levels. At Lowbanks it is a little lower than the modern storm beach. This beach confirms Fairchild's conclusion that the direction of tilting in the eastern part of the Lake Erie basin is more nearly north than it is farther west.

The Fort Erie beach has not yet been identified farther west or southwest, but it seems probable that near the Algonquin hinge line, about 30 miles southwest of Buffalo, it becomes horizontal 15 to 25 feet below the present lake level and so continues westward. It is perhaps possible that the Fort Erie beach corresponds to the submerged shore line found by Moseley at the west end of the lake, but it is probably more deeply drowned. This beach is almost

[1] See Goldthwait's isobase map: Bull. Geol. Soc. America, vol. 21, 1910, p. 233.

certainly the correlative of the Port Huron-Chicago stage of Lake Algonquin, and perhaps also of Early Lake Algonquin when the volume of discharge at Buffalo was large and Lake Erie stood at high stage.

TRANSITION TO LAKE IROQUOIS.

After the separation of Lakes Erie and Ontario into two independent lakes conditions changed rapidly. The ice front rested against the hills south of Syracuse, N. Y., and the outlet was eastward along its front. Several of the old cataract sites and outlet channels on the hills south of Syracuse are related to this shifting outlet river, though in all probability some of them are older than the Wisconsin glaciation. In fact, it has been shown by Fairchild[1] that the whole front of the escarpment from the Mohawk Valley to Ohio is marked with similar channels of drainage along the border of the ice. The slope is relatively steep, so that every movement of the ice front forward or back was exceptionally effective in raising or lowering the level of the lake waters to the west. This unstable condition was probably most marked while the waters were finally settling down to the Iroquois level during and after separation from Lake Erie. The transition stages and the lower stages confined to the Lake Ontario basin must have undergone many changes of level, and these probably account in part for the alternations of glacial and lacustrine formations which Spencer[2] describes as occurring in the Whirlpool-St. David gorge at Niagara.

GLACIAL LAKE IROQUOIS.

After the separation of Lake Erie the waters in the Lake Ontario basin became independent, except as they received the overflow of the upper lakes through rivers or were for a brief time merged in open connection with the sea. In the present state of knowledge the establishment of synchronous events in the history of these waters and those of the upper lakes is no easy task, for while much is now known concerning Lake Iroquois and Gilbert Gulf, much also remains to be learned. The critical areas of Lake Iroquois showing the correlation of its beaches with positions of the retreating front of the Lake Ontario ice lobe have not yet been studied. Since the time of the earlier studies by Spencer, Gilbert, and the writer, Coleman's investigations of the Iroquois and marine beaches have brought out many important facts showing the effects of the great uplift in deforming and warping all of the beaches and in splitting the Iroquois into a number of vertically diverging strands in the northeastern part of the basin. But the data on some of the critical points are still too few to yield satisfactory numerical values for altitude and time relations.

Most important in its relations to these water bodies is the ancient Algonquin outlet channel. Near Kirkfield and at Fenelon Falls this channel is a mile wide, and its scoured floor and faint shore markings show that the water in it was 20 to 35 feet deep. It is well developed and shows no sign of delta formation from its head at Kirkfield to Peterboro, where the extensive gravelly plain seems to mark its delta in Lake Iroquois. Coleman[3] shows that the delta is in a restricted tributary valley and in all probability marks a level slightly above that of Lake Iroquois, but no serious doubt has been cast upon its general correlative relation to that lake. This delta and the absence of other deltas above it show that Lake Iroquois was already in existence when Algonquin River began to flow, and the strength and magnitude of the delta show that the land in the region of Lake Iroquois was stable and unaffected by uplifts for a relatively long time. This was in the Kirkfield stage before the Algonquin uplift.

In 1894 Gilbert found that the Algonquin outlet channel does not stop at Peterboro, but "continues with undiminished strength" down Trent River to the present level of Lake Ontario at Trenton. The writer made the same observation in the fall of 1893, except that the channel near Trenton seemed to him somewhat smaller and less capacious than that at Fenelon Falls and less thoroughly scoured; this, however, may be an error. If the old channel really extends

[1] Fairchild, H. L., Glacial waters in the Lake Erie basin: Bull. New York State Mus. No. 106, 1907; Glacial waters in central New York: Bull. New York State Mus. No. 129, 1909.
[2] Bull. Geol. Soc. America, vol. 21, 1910, pp. 433-434.
[3] Coleman, A. P., The Iroquois beach in Ontario: Bull. Geol. Soc. America, vol. 15, 1903, pp. 357-358.

to present lake level at Trenton, without any indication of stopping there, it may pass 30 feet or more below that level and out to the east along the Bay of Quinte.

The great uplift which deformed the shore lines of Lakes Algonquin and Iroquois began a long time after the establishment of the Kirkfield outlet—at least long enough after to allow for the building of the Peterboro delta and for the making of strong shore lines over a large area of the upper lakes. Coleman [1] confirmed Gilbert's earlier observation that the Iroquois beach splits up into a number of strands, and he found that they diverge in altitude in a direction N. 20° E. from a line passing about through Quays, 6 miles north of Port Hope. Coleman considers that south of this line the same strands diverge southward in reverse order and that all but the last were submerged and obliterated. The line through Quays was therefore a nodal line, and it is very significant to find that when produced parallel with the other isobases it passes into the former outlet of Lake Iroquois at Rome, N. Y. But at present the Iroquois beach at Quays is 97 feet higher than the same beach at Rome, apparently showing that the post-Iroquois uplifts have had a stronger northward component than the earlier uplifts, for their isobases run more nearly east and west.

GLACIAL LAKE FRONTENAC.

When the ice sheet had retreated in the St. Lawrence Valley to the northern angle of the Adirondacks it opened a new outlet somewhat lower than that at Rome, N. Y. A strip along the mountain side on the slope toward Lake Champlain was scoured bare by that outlet river and is now known as "The Rock." This scoured channel ends in a sort of coarse delta formation 3 miles west of West Chazy. This stage of the lake waters was rather brief, and since the ice barrier which supported it rested on the Frontenac axis of pre-Cambrian rocks, it may be called glacial Lake Frontenac. A definite shore line has not yet been identified with this lake stage.

GILBERT GULF.

After the withdrawal of the ice barrier and the fall of Lake Frontenac the sea entered the basin of Lake Ontario. The duration of the marine occupation was probably short, and the connection was through a shallow strait 25 or 30 miles wide. Gilbert traced the marine beach on the south side of the St. Lawrence more than 25 years ago, following it from Covey Hill, Quebec, near the international boundary, southwestward to Oswego, N. Y., where it passes under the present level of Lake Ontario. Fairchild [2] named the marine waters in the Lake Ontario basin Gilbert Gulf.

On the Canadian side Coleman traced the marine beach from a few miles west of Prescott, where he found the last of the Pleistocene marine shells, westward into the basin of Lake Ontario.[3] Near Prescott the altitude of this beach is given as 350 feet above sea level. In 1896 what appeared to be the same upper marine limit was observed by the writer at Welch's siding, 3 miles north of Smith Falls, at 460 feet. At Brighton, 6 miles southwest of Trenton, Coleman gives it as 309 feet. From Brighton to Prescott the beach rises 41 feet in about 120 miles, or about one-third foot to the mile. But this is nearly on the line of its isobase, for from Prescott to Welch's siding it rises 110 feet in about 35 miles, or more than 3 feet to the mile. The direction of most rapid rise for the plane of the marine beach is therefore nearly due north in this area. At Belleville the altitude of the marine beach is given as 323 feet, and it is calculated that at Trenton it is close to 320 feet. Thus, if it reached present lake level at Trenton, Algonquin River must have descended 74 feet or more below the marine beach.

At first glance it seems hard to believe that the waters of the Lake Ontario basin could have fallen so far while Algonquin River was still flowing. But during the later part of the Kirkfield stage of Lake Algonquin the retreating ice was uncovering critical ground at the northern angle of the Adirondacks, and large and relatively sudden lowerings of the water level

[1] Bull. Geol. Soc. America, vol. 15, 1903, pp. 359, 363.
[2] Fairchild, H. L., Gilbert Gulf (marine waters in Ontario basin): Bull. Geol. Soc. America, vol. 17, 1907, p. 112.
[3] Marine and fresh-water beaches of Ontario: Bull. Geol. Soc. America, vol. 12, 1901, map, p. 130.

were inevitable. The duration of the Kirkfield stage was relatively long and the uplifts were spasmodic and not steady and even. From the beginning of Early Lake Algonquin to near the close of the Kirkfield stage no uplift occurred, so far as known. As the facts now stand, no satisfactory interpretation of the Algonquin channel between Peterboro and Trenton has been found.

If the supposed extension of the channel to Trenton is correct, it introduces a problem of much difficulty and seems to suggest an oscillation of the ice front even greater than that which preceded the building of the Port Huron morainic system. It does not seem possible that this episode of the lake history can be settled until more field studies are made.

Coleman's conclusion that the waters were backed up on the southern and western shores of Lake Iroquois by the uplift is confirmed by well-defined remains of an early Iroquois strand found by the writer north of Lockport and 32 feet below the main Iroquois beach.[1]

[1] Niagara folio (No. 190), Geol. Atlas U. S., U. S. Geol. Survey, 1913, p. 12 and surficial-geology map.

CHAPTER XXII.

THE NIPISSING GREAT LAKES.

By Frank B. Taylor.

LOCATION AND AREA.

The term "Nipissing Great Lakes" is applied to the waters of the upper three Great Lakes during the stage immediately following the final disappearance of the ice. The name is used in the plural form, because the Lakes at that stage were almost as distinctly separated as they are to-day. Lake Superior was connected with Lake Huron by a narrow strait or sluggish river without falls. Lake Michigan was connected with Lake Huron by the same strait that connects them now, except that the water stood about 50 feet higher, and also by a much narrower, shallower passage eastward from Little Traverse Bay. (See Pl. XXVII.) The outlet of the lakes, however, was eastward from the northeast angle of Georgian Bay instead of through Lakes Erie and Ontario, as now.

The area covered by the Nipissing Great Lakes was not very different from that now covered by Lakes Superior, Michigan, and Huron, including Georgian Bay. The reason for this lies mainly in the facts that the water plane of the Nipissing Lakes lay little above that of the present lakes and that the lands bordering their northern parts then, as now, were high and had relatively steep lakeward slopes.

Knowledge concerning the beginning of the Nipissing Great Lakes and the transition to them from Lake Algonquin is rather meager, but the condition of the lakes themselves and the transition from them to the present lakes is clearly recorded in the beaches.

EARLY LITERATURE.

As a distinctly recognized feature the Nipissing beach did not make its appearance in the literature of the lake region until a comparatively recent date. Only one or two of the references of the early writers to the "lake ridges" in New York, Ohio, Michigan, and Ontario appear to apply to the Nipissing beach. Whittlesey seems to have seen it in the Green Bay region, and early explorers in the northern parts of the area occasionally referred to "terraces" on the shores of Lake Superior that may have belonged to it.

In his discussion of the relation of the Great Lakes to Niagara Falls, Gilbert presented a map showing the supposed outlines of the upper lakes at the time of their discharge past North Bay to Ottawa River.[1] Gilbert visited North Bay in 1889 and went down the course of the old outlet river as far as Talon Lake. He clearly inferred the existence of such a beach as the Nipissing, but he estimated its deformation as being much greater than that which has actually been found. He identified the beach now known as the Nipissing only at the head of the outlet at North Bay, his outlines for other parts of the lake being wholly different from the true ones.

Wright visited North Bay and Mattawa in 1892 and saw the beach at the former place and evidences of the outlet river at the latter.[2]

In his earlier writings and even in his description of Lake Algonquin Spencer makes no more definite mention of the Nipissing beach than the general statement that along the south side of Georgian Bay there is "a numerous series of beaches extending from 28 feet down to the water level." Not until a later time did he recognize the existence of the outlet at North Bay.[3]

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[1] Gilbert, G. K., The history of the Niagara River: Sixth Ann. Rept. Commission of State Reservation at Niagara, 1890, p. 72 and Pl. IV.

[2] Wright, G. F., The supposed postglacial outlet of the Great Lakes through Lake Nipissing and the Mattawa River: Bull. Geol. Soc. America, vol. 4, 1892, pp. 423–427.

[3] Spencer, J. W., Deformation of the Algonquin beach and birth of Lake Huron: Am. Jour. Sci., 3d ser., vol. 41, 1891, p. 16.

The correlation of a particular beach in the Lake Superior and Lake Michigan basins with the outlet at North Bay was made in 1893 by the writer on an excursion in company with Dr. F. S. Pierce, of Philadelphia, and was published in 1894.[1] Since that time the beach has been studied by several students of the lake history who have worked in the upper lake region, and it has been mapped in considerable detail on all shores except those north and east of Lake Superior, north of Lake Huron, and north and east of Georgian Bay.

OUTLET.

The outlet of the Nipissing Great Lakes was at North Bay, Ontario, on the northeast shore of the modern Lake Nipissing. Later, differential uplift raised North Bay and gradually drove the waters back to Port Huron, inaugurating a transitional two-outlet stage which ended with the closing of the North Bay outlet and the transfer of the entire discharge to Port Huron, thus terminating the existence of the Nipissing Great Lakes.

The North Bay outlet river, or "Nipissing-Mattawa River,"[2] after passing a swampy col, amid glaciated bosses of crystalline rock, chiefly gneiss, passed down Mattawa River to Mattawa, where it joined Ottawa River and followed it, at first to glacial lakes and later to the sea, which occupied the St. Lawrence and Ottawa valleys at that time.

Mattawa River is composed mainly of a chain of lakes connected by short, rapid streams. Some of the lakes are long, narrow, and deep, lying in canyon-like valleys 200 to 300 feet wide, with water 100 to 300 feet deep, bordered by precipitous walls 100 feet or more high.[3]

The Nipissing beach is strongly marked along the north side of the col a mile north of the Canadian Pacific Railway station in North Bay[4] but is poorly developed along the south side, which was an archipelago of crystalline islands largely bare. The col swamp extends eastward to the head of Trout Lake, beyond which the outlet river leads through Turtle Lake, descends rapidly northward to the head of Tolon Lake, leaves the latter by a cascade of 30 or 40 feet, and passes through several lakes below. The lake beds show no clear evidence of the outlet river, but some of the intervening stretches record the scour of a great river. In some places the cross section of the scoured bed and the indicated velocity of the current show the river to have had about the same volume as St. Clair River of to-day; and this would be expected if this outlet carried the discharge of the same lakes after the ice sheet had ceased to contribute to them. The writer made a canoe trip down Mattawa River from North Bay to its junction with the Ottawa in 1896 and later published an account of some of the evidences of the presence of the outlet river.[5]

Though the erosion in the outlet channel is too slight to signify by itself that the river endured for a great length of time, other features indicate that its life was by no means short. It is to be remembered that its waters were drawn from clear lakes, that they had passed through the long channel of French River and through the basin of the modern Lake Nipissing before they reached the col at North Bay, and that for much more than half the length of Mattawa River they had flowed through deep narrow lakes. It is certain, therefore, that they were free from the coarser grades of sediment that might otherwise have been most efficient tools of erosion. Probably, therefore, the amount of erosion accomplished by this river is relatively small for the time it flowed.

The relatively strong Nipissing beach at the head of the outlet and on the shores of modern Lake Nipissing is also significant of the time involved, for at the time of the full discharge

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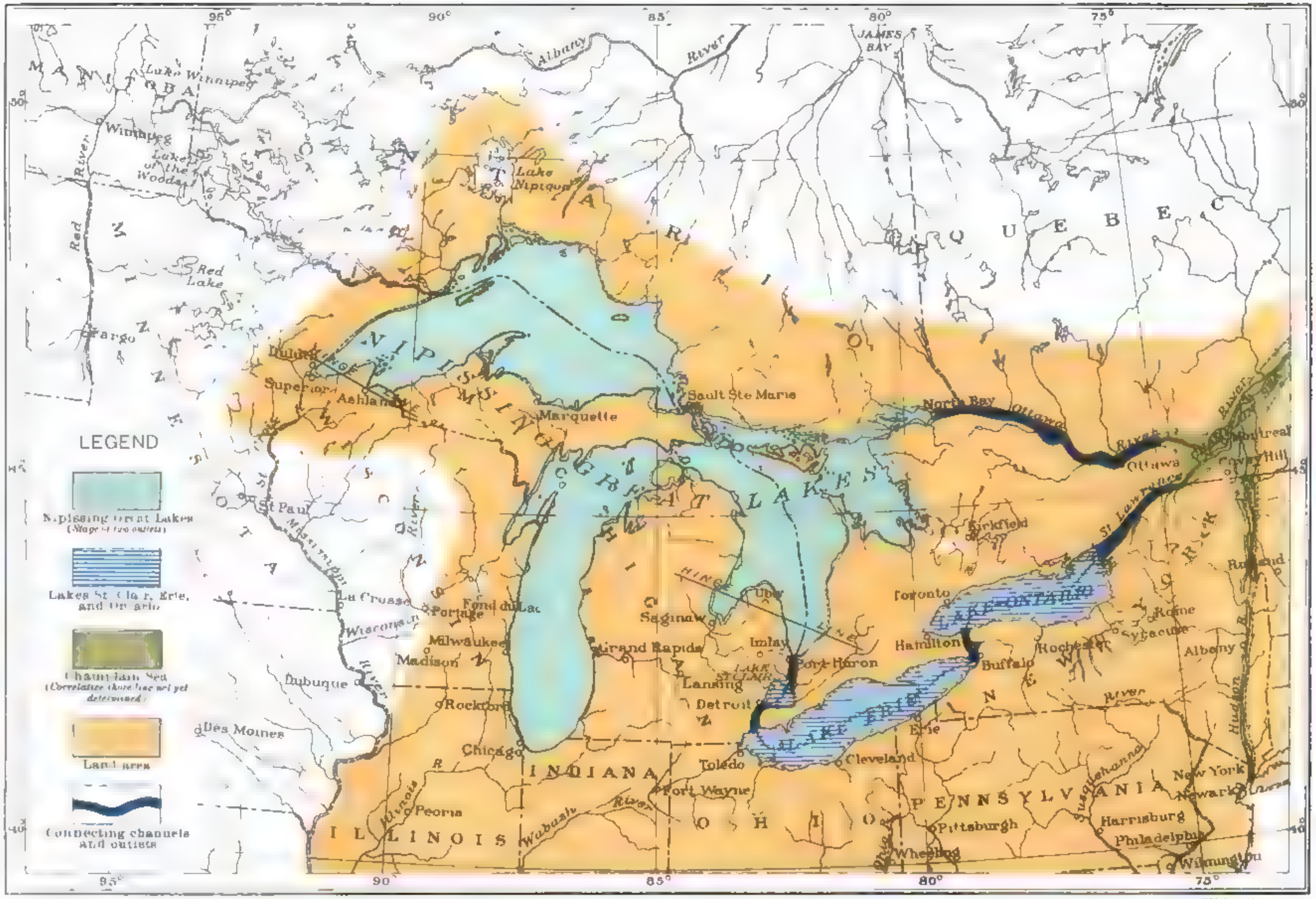
[1] Taylor, F. B., A reconnaissance of the abandoned shore lines of the south coast of Lake Superior: Am. Geologist, vol. 13, 1894, pp. 366-371.

[2] Taylor, F. B., The Nipissing-Mattawa River, the outlet of the Nipissing Great Lakes: Am. Geologist, vol. 20, 1897, pp. 65-66.

[3] Much detailed information concerning Mattawa River and its lakes may be found in the report of R. W. Ells and A. E. Barlow in The physical features and geology of the route of the proposed Ottawa Canal between the St. Lawrence River and Lake Huron: Trans. Royal Soc. Canada, 1895. The report gives table of altitudes and many soundings.

[4] In the writer's early paper (The ancient strait at Nipissing: Bull. Geol. Soc. America, vol. 5, 1893, pp. 620-626) an error was in some unaccountable way made both in the map and the text. The name "Nipissing beach" is there attached to a beach lying north of the water tower and having an altitude of 743 feet, whereas the real Nipissing beach lies along the base of the bluff south of the water tower and has an altitude of 698 to 700 feet. Unfortunately this error was repeated in a later paper (The second Lake Algonquin: Am. Geologist, vol. 15, 1895, p. 166).

[5] The scoured bowlders of the Mattawa Valley: Am. Jour. Sci., 4th ser., vol. 3, 1897, pp. 208-218. The Nipissing-Mattawa River, the outlet of the Nipissing Great Lakes (abstract): Jour. Geology, vol. 5, 1897, p. 220; Science, Jan. 15, 1897, p. 90.



MAP OF NIPISSING GREAT LAKES AND CORRELATIVES

By Frank B. Taylor and Frank Leverett

A. HOEN & CO. BALTIMORE

100 0 100 200 300 Miles

1914

through this outlet the expanse of the waters in the basin of the modern Lake Nipissing was very little greater than it is now and was much too small for the generation of powerful waves like those of the Great Lakes. The strong beach in this basin is therefore an indication that wave action lasted for a considerable time. Account must also be taken of the great strength of the Nipissing beach near the isobase of North Bay on the north shore of Lake Superior, which seems to indicate that the water plane of the Nipissing Lakes lasted considerably longer than that of the succeeding transitional two-outlet stage.

In the early part of this closing two-outlet stage a very small discharge probably went by way of Illinois River at Chicago, for the col there is only 8 feet and the Nipissing beach about 15 feet above the modern lake. The latter measurement, however, is the top of the beach ridge, and the water surface was probably 3 or 4 feet lower. This small discharge at Chicago ceased as soon as the outlet at Port Huron had cut down 3 or 4 feet.

NIPISSING BEACH.

NAME.

The name "Nipissing beach" has from the first been applied to the shore line now known to have been formed during the two-outlet stage of the lakes, when the discharge was deserting North Bay and returning to Port Huron and the Nipissing Great Lakes were coming to an end. This shore line is therefore, in reality, the beach of a transition stage, but it is so strongly developed and is so prominent around all the shores of the upper lakes that it has become firmly known as the Nipissing beach, in spite of the fact that this name properly belongs to the slightly older beach made by the Nipissing Great Lakes when their whole discharge passed eastward to Ottawa River.

After the formation of the true Nipissing beach the whole region was differentially elevated, depressing the water plane to the north and raising it to the south of the isobase of the North Bay outlet. This isobase runs about west-northwest, and only a little of the Lake Superior of that time lay north of it. The whole area of the Nipissing Great Lakes south of this line was flooded by the backing up of the water, and the original Nipissing beach and its successors, up to the time when the Port Huron outlet equally divided the flow with the North Bay outlet, were submerged and probably to a large degree destroyed. Hence the original Nipissing beach in unmodified form is to be seen, if anywhere, only in a small area in the northeast corner of Lake Superior, and it seems easier to qualify the name of that beach by calling it the "first" or "original" Nipissing beach than to try to change the name by which the beach of the transition or two-outlet stage has come to be known. Accordingly, the established usage is followed here.

DISCRIMINATION FROM ALGONQUIN BEACHES.

The differential elevation which affected the Nipissing beach appears to have hinged on the same line as that which affected the highest Algonquin beach.[1] South of this line, therefore, in the basins of Lakes Huron and Michigan lies the area of horizontality, so far as relates to this beach. Within this area in both basins measurements of the altitude of the Nipissing beach vary between 14 and 16 feet above present lake level, the mean being in general about 15 feet.

In the area of horizontality the relation of this beach to the Algonquin shore line is such that for short distances in many places it is impossible to distinguish the two. Both lie in horizontal planes, the Nipissing being 10 to 12 feet below the Algonquin. Where the Algonquin is represented by several strong ridges descending by short steps toward the lake, the Nipissing beach may appear as one of these ridges without any distinguishing characteristics.

This relation, however, obtains for only relatively short distances. Within a mile or two from nearly all such places some distinguishing characteristic or evidence of discordance

[1] This relation seems clearly established in the basin of Lake Michigan, but owing to the difficulty of determining the Nipissing beach, it remains somewhat uncertain in the basin of Lake Huron. In the basin of Lake Superior the two hinge lines may be separated by a considerable interval.

that shows unconformity will be found. Where any considerable width of beach deposits intervenes between the Nipissing and the present shore it is likely to be occupied by rather light beach ridges set very close together, with the Nipissing beach as the uppermost. Where the Algonquin is represented by several ridges, they are as a rule heavier and less sandy than those below the Nipissing. Only where the Nipissing derived fresh material from the cutting of some great bluff or from outcrops of limestone or shale is it likely to be as pebbly or gravelly as the Algonquin.

On certain shores the Nipissing beach has been largely and in places almost wholly cut away at present lake level. This is notably the case along the east side of the "thumb" north of Port Huron, on both sides of Lake Michigan, and on the east side of Lake Huron.

DISTRIBUTION IN MICHIGAN.

Port Huron to Port Austin.—The shallow embayment between Port Huron and Lakeport has a faint Algonquin beach at its back and a stronger one a mile farther out. Outside of these the Nipissing and lower beaches complete the filling of the old bay and bring the shore to a straight line.

About a mile north of Fort Gratiot a sandy bench appears in front of the Algonquin. It extends north, widening within 2 miles to a mile and continuing with this width for about 3 miles, to about half a mile south of Lakeport, where the present lake has cut it away. The outer part of this bench is mostly slightly below Nipissing level, but back from the lake it rises gradually to the base of the Algonquin ridge. So much of it is close to the Nipissing level that it is presumably mainly of that age. Almost the whole bench is covered with fine sand, much of it wind blown and heaped into small dunes.

Northward from Lakeport the Nipissing beach has been cut away for many miles. What is possibly a very small remnant of it appears just south of Stevens Landing, 6 miles to the north; but from there northward it is gone for over 40 miles, or to a mile north of White Rock. From its beginning north of White Rock to the mouth of Cooper Creek, 3 miles north, the Algonquin beach has been cut away by the Nipissing waves, but beyond that both beaches are generally present and the Nipissing beach is substantially continuous around the remainder of the "thumb" and Saginaw Bay to Au Sable River.

Throughout this stretch the Nipissing beach is conspicuously developed in few places. For short distances it cuts into the Algonquin beaches and thus shows distinct discordance, and for a few very short distances it is cut away by the present lake. One such cutting appears about 3 miles southeast of Huron on the outer part of the "thumb." Farther on, near Grindstone City, at Pointe aux Barques, and near Port Austin it is cut away for short distances.

Port Austin to Bay City.—Between Port Austin and Caseville the Nipissing beach is so much obscured by dunes that it is not easily distinguished. Between Caseville and Bayport it is mainly sandy, but at some points is a ridge of pebbles and shingles. From Bayport past Sebewaing to Quanicassee it is generally a gravel ridge or group of ridges of nearly the same height. For several miles east of Essexville also it is gravelly.

Bay City to Au Sable River.—From Bay City northward past Lengsville to Saganing, where the hinge line of the Algonquin and Nipissing beaches crosses the west shore of Saginaw Bay, the Nipissing beach is a belt of sandy ridges half a mile to a mile from the lake shore. A mile or two north of Alabaster the cliff back of the beach is 60 to 70 feet high and the bench a quarter of a mile wide. The beach is a wave-cut bench that carries ridges to the mouth of Tawas River. Thence through Tawas and East Tawas and beyond to Au Sable River it is a low, broad ridge or belt of sandy, gravelly ridges half a mile to a mile wide. From East Tawas it lies generally about a mile back from the shore. An extensive swamp behind it stretches 6 or 7 miles northeast from Tawas Lake.

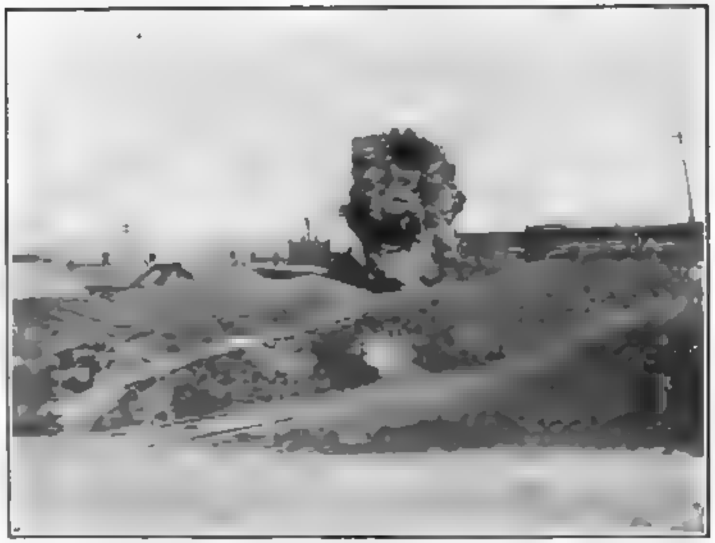
Au Sable River to Mackinaw City.—At Alabaster and Tawas the vertical separation of the Algonquin and Nipissing beaches has noticeably increased, and it continues to increase slowly northward to Alcona. Between Devil Lake and Presque Isle it increases more rapidly.

A. NIPISSING BEACH GRAVELS SOUTHEAST OF ROGERS, MICH.

B. SLEEPING BEAR POINT, LEELANAU COUNTY, MICH.

A. SUGAR LOAF ROCK, MACKINAC ISLAND, MICH.

A remnant of wave erosion at the Algonquin level.



B. STACK IN ST. IGNACE, MICH.

A remnant of wave erosion at the Nipissing level.

C. MACKINAC ISLAND FROM ROUND ISLAND, LOOKING NORTHWEST.

The strength of the Nipissing as an individual beach becomes more and more apparent farther north as it becomes more widely separated from the Algonquin.

From Au Sable River northward the Nipissing beach runs for about 11 miles, or nearly to Greenbush, as a belt of sandy, gravelly ridges. This beach forms the retaining barrier at the southeast end of Van Etten Lake, and two of its prominent ridges inclose the long, narrow lagoon of Cedar Lake.

At Harrisville the Nipissing is cut away for a short distance, but it is well formed toward Sturgeon Point and at Alcona. Between Alcona and Ossineke the beach carries the highway for much of the distance through a great swamp. It is strongly developed as a heavy gravelly spit a little back from the point that projects halfway between Alcona and Ossineke.

From Ossineke to Alpena the Nipissing shore line is a great belt of sandy ridges. The sand is mainly fine and is considerably modified by wind but forms no large dunes. It is as distinct as along the front of the Au Sable delta. South of Alpena it incloses Devil and Mud lakes. Just east of Alpena it passes off the belt of sand and enters a region of limestone thinly covered with drift, where it becomes predominantly a pebbly, gravelly ridge or belt of ridges, in some places changing to a wave-cut bench with more or less of a cliff behind it and in a few places becoming simply a wave-washed rocky slope.

At Alpena the Nipissing beach stands over 30 feet above the lake, more than twice as high as in the area of horizontality. This widening of the vertical interval below it permits better expression for the so-called post-Nipissing raised beaches below, which were formed by lakes that bore the same relations to each other and had the same outlet as those of to-day, the only difference being that the earlier lakes were somewhat more intimately connected and that the water stood higher in the Straits of Mackinac and at Sault Ste. Marie than it does now.

East of Alpena the Nipissing beach appears as a gravelly ridge lying about a mile back from the shore north of Whitefish Bay. Fragments of it extend for some distance south onto the peninsula. At El Cajon Beach, 6 miles east of Alpena, the Nipissing shore line is a strong finely formed gravel ridge at the base of a rather low wave-cut cliff. A mile farther north it forms a high gravelly barrier which shuts off Grass Lake from Lake Huron. Thence northwest to the south end of Grand Lake it runs in great strength, in places as a heavy gravel ridge at the base of a low cliff and in places as a strong wave-cut bench with only a bowldery or rocky slope for some distance below the notch. Near Bell it turns west past the south end of Grand Lake and ends against a vertical cliff of limestone which forms the west side of this lake for several miles.

On the peninsula of Presque Isle along the east side of Grand Lake the Nipissing beach is finely developed at several localities. Both north and south of Presque Isle post office there are areas over a mile wide and 2 to 4 miles long around which the beach is strongly developed as a prominent gravel ridge. It is particularly strong as a great spit or deep-water bar projecting southeast to Presque Isle from a larger island a mile or two northwest. The quantity of coarse, clean gravel in these deposits is enormous. The body of the peninsula is limestone with very little drift upon it, and this rock has been the principal source of the gravel. Beach gravels are also finely developed on the outer part of the narrow peninsula which extends to Presque Isle lighthouse, but are below the Nipissing level.

From the north end of Grand Lake the beach extends to Little Trout River mainly as a wave-cut bench and cliff, but in some places as a barrier ridge inclosing swampy land. Beyond the river it lies farther back from the shore and is chiefly a wave-cut cliff at the back of a sandy belt as far as Crawford's quarry, but between that place and Rogers it is a wave-cut cliff with a wide bench covered with gravelly beach ridges. This accumulation of gravel is one of the finest developments of the Nipissing beach on the southern peninsula of Michigan. (See Pl. XXVIII, *A*.)

From Rogers for 7 or 8 miles northwest the cliff marking the Nipissing beach is about 40 feet high. It turns westward at Fortymile Point, from which it continues as a cliff to the east side of Hammonds Bay, where it once more becomes a broad belt of sandy and gravelly

ridges which separate three or four small lakes from Lake Huron. This sandy belt terminates near Grace Harbor, beyond which cliffs freshly eroded by the present lake extend northwest and west to Cheboygan lighthouse. This part of the shore was seen only at Greens Landing, where only a narrow strip of the Nipissing bench remains. It seems probable that the Nipissing beach has been cut away by the present lake in much of this interval. A mile east of the Cheboygan lighthouse the beach turns inland and runs southwest to Cheboygan River. A great sandy flat, the west half of which is swampy, stretches 4 miles east from Cheboygan

At Cheboygan the Nipissing shore line makes a considerable excursion inland, forming an irregular strait reaching through to the head of Little Traverse Bay. It extends up Cheboygan and Black rivers to or very nearly to Black Lake. This lake appears to stand almost exactly at the level of the beach, but the precise relationship has not been determined. The waters of Lake Huron at the time of the Nipissing Great Lakes extended as a narrow strait into the basin of Mullet Lake, around which the Nipissing beach is strong, mainly as a cut bench with a lake cliff back of it and light sandy ridges below. From the west side of the lake a narrow, swampy trough extends 5 miles northwest toward Douglas Lake. Up this the waters at that time extended for several miles.

Again contracting to a narrow strait, the waters extended up Indian River to Burt Lake, and around its steep shores the Nipissing beach is nearly everywhere distinct though not strong. Extending westward over a great swamp these waters filled the basins of Pickerel and Crooked lakes and passed through to Little Traverse Bay. At Conway the strait was a little more than a mile wide, but it broadened to 2 miles at Kegomic. The relatively great strength and sharpness of this beach on the shores of these small lakes indicate a relatively long pause of the waters at this level.

About a mile south of Cheboygan on the east side of the river many fossil shells were found a little below the level of the Nipissing beach. The following forms were identified by W. H. Dall, two or three others being too fragmentary for certain recognition: *Sphærium striatinum* Lamarck, *Unio luteolus* Lamarck, *Limnæa elodis* Say, and *Goniobasis depygis* Say.

In the western part of Cheboygan the Nipissing beach is a wide sandy bench with a cliff 10 or 15 feet high at its back. It weakens considerably southward in the narrow passage to Mullet Lake, but is still distinct. Between Cheboygan and Mackinaw City the Nipissing beach is a bench carrying strong, gravelly, and sandy beach ridges, backed by a lake cliff 10 to 40 feet high and in one or two places 70 or 80 feet high. The Michigan Central Railroad follows the beach rather closely and lies most of the way on its bench. The present lake has cut heavily into this shore and at Lakeside has cut back to the Nipissing beach. At Freedom the beach is composed of heavy sandy and gravelly ridges. A mile south of Mackinaw City it is a wave-cut bench and bluff.

Islands.—The shores of Bois Blanc Island are rather low, but the interior rises above the level of the Nipissing beach, which encircles it about a mile inland. It has not been explored above the Nipissing level, but it certainly rises high enough to record the Fort Brady and probably the Battlefield beaches, though perhaps not high enough to record any of the upper Algonquin group. The Nipissing beach is well developed on Round Island as heavy gravel ridges and a low cliff.

On Mackinac Island the Nipissing beach is well developed on the northwest part and at the southeast end in the vicinity of the village. (See Pl. XXIX, *C.*) On the east side of the island and on the southwest side along the line of the great cliffs the beach has been almost entirely cut away. From Robinsons Folly to the Episcopal Church the beach is a strongly cut bench with a cliff 40 to 70 feet high at its back. Gravelly beach ridges run at the base of the cliff, but the drift is thin over the bedrock and the ridges are rather faint. The Mission House is on the highest beach ridge at that point and the wave-cut notch is just back of the hotel at a slightly higher level. This notch runs along the base of the bluff back of the Island House, the public school, and the Marquette Monument. This beach is cut away below Arch Rock. (See Pl. XXX.)

ARCH ROCK, MACKINAC ISLAND, MICH., FROM THE LAKE.

At the Episcopal Church the beach leaves the cliff and runs southwest as a great deep-water gravelly bar. The church is on the bar near where it leaves the cliff. Back of the Astor House and the city hall the clean coarse gravels of this bar are exposed to a depth of 20 feet or more, and excavations have shown that they extend at least 10 feet deeper. Back of the village there is a considerable body of marl and fine lake clay, along the top of which the great bar extends to the southwest corner of the Government pasture field. From the direction of the Grand Hotel another lighter gravel bar extends out from the bluff at a slightly lower level and joins the one mentioned above. Behind this cuspate bar, in the Government field, lies a depression about 30 feet deep and of considerable extent, which receives much water from several large springs that issue from the bluff. In wet seasons a small pond is formed, but in dry seasons it disappears, being drained by seepage through the gravel. A little east of the Grand Hotel the beach returns again to the bluff and runs along its base as a wave-cut bench. Northwest of the hotel the bench grows narrower and is finally cut away by the modern lake.

On the northwest part of the island, back of British Landing and for about a mile to the south, the beach is very strong. Back of the landing it forms a great deep-water barrier which runs south across a depression of considerable extent, above which it rises about 25 feet. A small swamp behind this barrier is drained by seepage through the gravel. At its south end the barrier joins a great cliff, and for nearly a mile to the south forms a wave-cut bench bearing many gravelly ridges and backed by a steep shale cliff 70 to 100 feet high. The barrier bar appears to have derived most of its material from the north by southward drifting along the shore. Around the north end of the island north from British Landing and for a mile down its east side the beach appears as a cliff 20 to 100 feet high with numerous gravel ridges on the slope below it. Pulpit Rock and Scotts Cave are developments associated with this beach.

All around the sides of the St. Ignace Peninsula the Nipissing beach is remarkably strong. Just north of the town one of the most remarkable gravel beds of this part of the country formerly stretched as a great deep-water barrier across a depression which runs westward across the peninsula. The gravel was rather coarse and very clean and white, being composed almost entirely of limestone pebbles. Most of the deposit has now been taken away and used for railroad ballast. On the west side of the peninsula from Point Labarbe to Gros Cap the beach is particularly fine. Two or three chimneys or stacks here and one in St. Ignace are relics of the shore erosion at the time of the Nipissing beach. (See Pl. XXIX, *B*.)

Mackinaw City to Traverse City.—West of Mackinaw City the Nipissing beach is a strongly cut bench and bluff on the north and west sides of McGulpin Point. On the east side of Cecil Bay the Nipissing beach runs for a short distance along the base of a cliff of limestone, but for most of the way it appears as a heavy belt of sandy ridges which forms the west barrier of French Farm Lake and continues thence west-southwest past Oneil Lake nearly to the shore of Sturgeon Bay. Here it turns south and looping around Wycamp Lake runs southwest to about 3 miles beyond Cross Village. North of Wycamp Lake it is a heavy belt of sand, but west of the lake toward Cross Village it is a high lake cliff. At Cross Village and for about 2 miles southwest it is a wide wave-cut bench with a cliff 80 or 90 feet high. Beyond this for 2 miles it has been cut away by the modern lake, the bluff rising more than 100 feet nearly vertical from the present shore. From 2 miles north of Middle Village it runs south as a high cliff for about 5 miles, to a point 2 miles north of Appleton, where it is again cut away by the modern lake for about 1 mile, the cliff on the present shore being unusually high. About a mile northwest of Appleton it reappears with a high bluff at its back and it continues in this form along all the north side of Little Traverse Bay past Harbor Springs and Wequetonsing and with a somewhat lower cliff past Conway to the vicinity of Oden. For 2 miles southeast of Appleton the Nipissing has cut away the Algonquin beach and has penetrated into morainic ground that rises considerably higher, producing a bluff over 125 feet high—probably the highest wave-cut bluff in this region. The beach and cliff are also finely developed in Harbor Springs and eastward. The bench of the Nipissing beach from Cross Village to the head of Little Traverse Bay is nearly everywhere

heavily paved with bowlders and stones derived from the cliff cutting and afford a rough measure of the amount of cutting accomplished. The passage eastward from Little Traverse Bay is now closed by a great belt of dunes that stretches across the head of the bay, but it was not closed by the gravels of the Nipissing beach.

At Bay View the Nipissing beach is considerably obscured by wind-blown sand. In the eastern part of the village a sharp bluff rises from a wave-cut bench covered by many low ridges of sandy gravel. But here as in some other places the old shore features are deceptive, because later wave work at a slightly lower level removed the Nipissing shore line. Between Bay View and Petoskey the beach is partly obscured by dunes and partly cut away by the present lake. In Petoskey and for some distance to the west the bluff continues with its base lower than the Nipissing level. At Bay Shore and at several points to the east small fragments of the Nipissing shore line occur, but for about 3 miles west of Bay Shore the beach is again cut away by the present lake. North of Burgess it reappears as a cliff and heavy sandy and gravelly ridges, which extend for 3 miles, to about a mile north of Charlevoix, where it is again cut away by the present lake.

On Beaver Island the Nipissing beach is finely developed around all sides, except the southern, on which for a mile or two it has been cut away by the present lake. Along nearly all the western side the beach is a tremendously strong, wide, bowldery, wave-cut bench with a steep cliff 50 to 100 feet high. On the east side the bluffs are much lower and the ridges along its base are gravelly and sandy. It is a fine gravelly bar at the old site of Cable's dock and constitutes the barrier which separates Lake Genesareth from Lake Michigan. About 3 miles north of Cable's dock it is cut away by the present lake for nearly a mile. At the north end of the island it is finely developed at Indian Point, and bars belonging to it inclose Faunt Lake on its west side. The gravel bars near the lighthouse, a mile east of St. James, are massive and finely developed.

On High Island the Nipissing beach is well developed and forms a barrier inclosing a small pond on its east side. It occurs also on Garden Island and probably on Hog Island.

The waters of the Nipissing Lakes entered Pine Lake at Charlevoix and left a light but very distinct shore line all around its shores. For 4 miles southwest of Charlevoix the present lake has cut away the Nipissing beach. From this on to a point a little south of Norwood it is a narrow bench and cliff. At Norwood it is marked by a wide bench and a high bluff. For 3 or 4 miles beyond it is again cut away, but from a point northwest of Eastport it is part of a sandy belt that skirts the shore as far as Elk Rapids. In this vicinity the Nipissing beach lies so little above Lake Michigan and so little below the Algonquin beach that it is less conspicuous and it is more generally cut away by the present lake.

The waters of this stage entered Elk, Round, Torchlight, and probably Clam and Grass Lakes also. From Elk Rapids to the head of East Bay the beach is cut away for much of the distance, but where it remains it is mainly a narrow cut bench with a low cliff at its back. In some places, however, it is a gravelly bar. Across the south end of East Bay it is a low sandy belt.

The east side of the Old Mission Peninsula is high and steep and the water is deep near shore. It has not all been explored, but so far as seen the Nipissing beach appears to be present along the greater part of it as a narrow bench and low cliff. In some places it has been cut away by the present lake. It runs around Old Mission Harbor as a belt of low, crescentic ridges inclosing two small ponds. Along the west side of the peninsula there are more stretches of low ground, although in general the shore is rather steep. From the Mission Point lighthouse for about 3 miles southwest the Nipissing beach is well defined along the back edge of the low, sandy shore. It is also formed in moderate strength around Bowers Harbor and on Marion Island and at most places along the shore southward to Traverse City. The sandy flat which forms the neck of the peninsula just east of Traverse City is mainly an accumulation of the Nipissing beach. But for this sand the peninsula would be an island.

Traverse City to Manistee.—In Traverse City the Nipissing beach encircles the head of the bay about a quarter of a mile from the shore and passes through the south part of the business section. It appears to deflect Boardman River to the west after it leaves Boardman Lake. The beach is not seen to advantage in the city, but in the suburbs both east and west it appears as a belt of sandy ridges. Northward on the west side of the bay it is well defined for several miles and forms the principal part of the barrier that incloses the small lake behind Traverse Beach. Two or three miles north of this small lake both the Nipissing and Algonquin beaches are cut away for two intervals of half a mile each. At Lees Point the deposits of this beach form the principal parts of the projecting cusp. At Suttons Bay the Nipissing beach is a belt of low sandy gravel ridges. Toward Omena it is a well-defined storm bar which ties the headland to the mainland. Thence to Northport it is a gravelly bench and low bluff.

Although generally well defined on the shores of Grand Traverse Bay, the Nipissing beach is considerably weaker than on the more exposed shores outside. In the two arms of the bay it is clearly developed in some places, but it is generally weak, especially toward their heads.

In the vicinity of Northport the beach increases in strength, especially on Lighthouse Point. Around Cathead Bay it is probably covered by dunes. Two small ponds, Mud and Leg lakes, have been shut off by barrier bars.

Southward from Cathead Point the Nipissing beach on the west side of the peninsula has been cut away everywhere except in fragmentary embayments that now remain between truncated headlands. From the point to Leland it is gone. On Lake Leelanau it is faintly marked on both sides of the inlet and is the wide sandy terrace on which the lower part of the village of Leland is built.

The Fox Islands were not visited, but the low altitude of the beach makes it practically certain it is present unless it has been cut away. On North Manitou Island it is a fairly strong sandy, gravelly bench with a low cliff back of it along most of the east shore, but it has been cut away on most of the remaining sides. On South Manitou Island it is recorded on the east side as a belt of gravelly ridges around the harbor, but it is probably cut away at most places on the other sides.

The beach reappears 3 miles south of Leland and extends around Good Harbor Bay to within a mile of Pyramid Point. Between Good Harbor and North Unity it is a great crescentic belt of sandy gravel ridges half a mile or more wide. The barrier formed by this belt incloses Traverse Lake and a small lake west of North Unity and has diverted the outlet of Traverse Lake 2 miles to the west.

On Sleeping Bear Bay the beach reappears about a mile north of Glen Arbor and forms well-defined sandy gravelly ridges to half a mile west of Glen Haven. Around Sleeping Bear Point and for 5 miles south the Nipissing beach is entirely removed. (See Pl. XXVIII, *B*.) In an embayment which begins 3 miles north of Empire and extends to that place it lies about a mile back from the shore as a belt of gravelly ridges not far below the Algonquin. Two small ponds in front of the Nipissing beach have been inclosed by modern shore drift and by dunes.

Along the bluffs at Empire the beach is entirely removed, but it begins again at Aral and runs around Platte Bay as a great belt of sandy ridges a quarter to half a mile from the shore. Around the west end of Crystal Lake the beach has been cut away.

Some low sandy ridges at Frankfort seem to belong to the Nipissing stage, but the embayment is small and wave action seems to have been weak. For 2 miles south of Frankfort the beach has been cut away, but in the small embayment at Herring Lake it occurs in faint development as sandy ridges. Beyond, it has been cut away for 2 miles, but for a mile or so north of Arcadia it is present in moderate strength as a gravelly ridge.

From Arcadia to a mile south of Portage Lake the Nipissing beach is gone. It is gone also for 3 miles north of the inlet at Manistee. Around Portage and Bar lakes, however, it is quite distinct, though not strong. Around both of these lakes the Algonquin appears to be absent. (See p. 428.)

The hinge line for the Nipissing beach on this shore appears to be at or near Herring Lake, so that places south of Herring Lake are within the area of horizontality. The identity of the beach with one farther south in Michigan, as described by Mr. Leverett, and with its extension around the south and west sides of Lake Michigan, as observed by Leverett, Alden, and Goldthwait, seems to be beyond reasonable doubt. In these latter regions it stands in the same relation to the present lake and to the Algonquin beach as does the beach described above in the south part of Lake Huron. (See p. 357.)

NIPISSING BEACH IN OTHER PARTS OF THE UPPER GREAT LAKES BASINS.

Since the writer's reconnaissance of 1893 the Nipissing beach has been studied in considerable detail on the shores of Green Bay in Wisconsin and Michigan by Goldthwait and by Hobbs. The beach is strong on those shores and is generally easy to recognize. Goldthwait measured its altitude instrumentally at many places in Wisconsin and Hobbs at several in Michigan.

In Ontario the Nipissing beach was not particularly noted by Spencer in his early work. The writer's early investigations in Ontario included this beach at numerous localities, but the more detailed work and the instrumental measurements of its altitude were made by Goldthwait and the writer in 1908. The beach is developed in great strength along the southern shores of Georgian Bay, especially on the eastern shore of the Saugeen Peninsula and the north shore of the Penetang Peninsula. The region of Lake Simcoe was elevated before the time of the Nipissing beach and was much too high to record it. The beach extends a few miles above Coldwater from the head of Matchedash Bay, but at this village it lies 83 feet below the surface plane of Lake Simcoe.

The writer's early reconnaissance included observations on the Nipissing beach at many points on the northern peninsula of Michigan and on the south shore of Lake Superior. Since that time Russell and Lane have made some further studies and Mr. Leverett in particular has made a much more thorough investigation. The beach has been found in strong development along the entire stretch of the south shore, except at the west end near Duluth, in which vicinity it appears to pass under the level of the present lake. Mr. Leverett finds it apparently passing beneath the present lake about at Washburn, Wis., on Ashland Bay, and again on the west slope of the Bayfield Peninsula, the greater part of the peninsula showing the mark of this beach.

In the area of horizontality in the basins of Lakes Huron and Michigan the Nipissing beach is about 15 feet above present lake level. The uplift which deformed this beach raised the barrier at Sault Ste. Marie so as to place Lake Superior 20 feet above Lake Huron or about 5 feet above the level of the beach in the area of horizontality to the south. From this it may be inferred that if the area of horizontality reaches any part of Lake Superior (and it is obvious that it could do so only at the west end of the lake, where the Nipissing beach descends to or passes below the present lake level), the beach made there before the barrier at Sault Ste. Marie was raised to its present height, supposing open connection at that time with Lake Huron, would now be submerged about 5 feet. This, apparently, is the present condition at the west end of the lake. But, as with the hinge lines in the Lake Huron and Lake Michigan basins, the apparent line here is determined by the backing up of the water, the real hinge being now submerged and lying a few miles farther south.

During the time of the full discharge of the Nipissing Great Lakes at North Bay a low stage prevailed in the region of horizontality, and the beach made then is below the two-outlet Nipissing beach and is now submerged. The same low stage affected the west end of Lake Superior, the lake surface at Duluth being probably 50 to 60 feet lower then than now, as indicated by the old bed of St. Louis River, now drowned in the bay west of Duluth. In all probability Lake Superior was then separated from Lake Huron by a sluggish river, which was later turned into a strait by drowning during the two-outlet stage, the deformation or tilting now seen in the Nipissing or two-outlet beach comprising only that part of the uplift which occurred after the two-outlet stage had been established. It was therefore this later uplift which produced the

drowning of the Nipissing or two-outlet beach at Duluth and raised Lake Superior to a position 20 feet above Lake Huron.

The Nipissing beach is everywhere so little above the water surfaces of the present lakes that it is almost always near the present shore, and hence is easily reached. In the northeast corner of Lake Superior it is 110 feet above the lake, but that shore is a high coast with steep slopes, so that even there it is near the present shore. It is only in the labyrinth of islands along the east side of Georgian Bay and the North Channel of Lake Huron and especially up the valley of French River to Lake Nipissing and North Bay that the Nipissing beach lies any distance inland. All of these northern regions are still in a wild forested state, and it is practically impossible to trace any of their beaches continuously.

Excepting Coleman's observations on the high beaches, the east coast of Lake Superior, between Peninsula Harbor and Sault Ste. Marie has not been explored. But Lawson and the writer have observed this beach at many places on the north and northwest shores. It was found also at Sault Ste. Marie, at Thessalon, at Algoma Mills on the North Channel of Lake Huron, and at North Bay.

Although these observations of the Nipissing beach on the northern shores are widely scattered, some of them being separated by intervals of more than 100 miles, yet this beach is so distinguished from all others by its great strength and individual characteristics that its identity seems to be beyond doubt at every locality where it has been reported. From these scattered observations some interesting facts have been deduced, the most important being that the strength of the Nipissing beach increases very perceptibly toward the north, attaining its greatest development in the most northerly part of the Lake Superior basin. This is significant when it is noted that the isobase of North Bay passes only a few miles south of the extreme northeast corner of Lake Superior, and that the original Nipissing beach was submerged in all the region south of the isobase of North Bay by the uplift that shifted the discharge to Port Huron. Along the isobase of North Bay the waves were at work not only during the beach of the two-outlet stage (known as the Nipissing beach), but before that, from the very beginning of the discharge eastward by North Bay. The character of the outlet channel in the Mattawa Valley shows that the whole discharge passed that way for a considerable time. South of the isobase of North Bay the only beach of this stage of the lakes now to be seen is that of the closing two-outlet stage. North of the isobase the beach of the two-outlet stage lies below the original beach of the North Bay outlet, but the isobase passes so near the northeast corner that the area to the north, in which the beaches are exposed, is very small, probably too small to show the relations clearly. Nevertheless, the greater strength and distinctness of the beach in the region of the isobase afford substantial proof of the correctness of this interpretation.

ALTITUDE.

In the Michigan and Huron basins the deformed portion of the Nipissing beach appears, as already stated (p. 449), to hinge on the same line as the Algonquin. South of the hinge line in both basins the Nipissing beach has an altitude of 595 to 597 feet, the average being about 596 feet. The observed variations in altitude are entirely within the normal variations in the height of a beach ridge made by the waves of a lake subject only to climatic and wind variations. The altitude of the Nipissing beach where measured instrumentally on the north and west of the southern peninsula of Michigan is given in the following tables, to which are added altitudes at North Bay, Ontario, and Sault Ste. Marie. The altitude of Lake Huron is taken as 581 feet.

Altitudes of Nipissing beach on the north and east of Lake Michigan.

Locality.	Altitude above sea level.	Height above Lake Huron.	Authority.
	Feet.	*Feet.*	
Sault Ste. Marie	[a] 651	70	Leverett.
Detour	[a] 632	51	Russell.
Mackinac Island (storm bar)	634	53	Goldthwait.
Mackinac Island (average normal bars)	631	50	Goldthwait and Taylor.
St. Ignace	628	47	Goldthwait.
Mackinaw City	629	48	Do.
Beaver Island (north)	623	42	Do.
Beaver Island (south)	616	35	Do.
Harbor Springs	615	34	Do.
Burgess	613	32	Do.
Charlevoix	611	30	Do.
Norwood	608	27	Do.
Northport	606	25	Do.
Omena (storm bar)	609	28	Do.
Leland	604	23	Do.
Suttons Bay	607	26	Do.
Elk Rapids	606	25	Do.
Acme	601	20	Do.
Traverse City	602	21	Do.
Aral	600	19	Do.
Frankfort	599	18	Do.
Herring Lake (gravel belt)	595	14	Do.
Arcadia	595	14	Do.
Onekama	597	16	Do.
Bar Lake	597	16	Do.

[a] By aneroid barometer.

The differences in the measurements on Mackinac Island are so great as to leave some doubt as to the height of the normal beach. Estimated from all the forms that seem normal and excluding the extra high storm beaches, the height is about 50 feet above the lake.

The beach at Omena is also a high storm bar. The measurements at Frankfort and Herring Lake are both on ridges that are strong but are not sharply defined.

On the west side of Lake Huron the altitude of the Nipissing beach was determined instrumentally only by Gregory and Cooper. The other readings are by either aneroid or hand level. The altitudes are given in the following table:

Altitudes of Nipissing beach on the north and west of Lake Huron.

Locality.	Altitude above sea level.	Height above Lake Huron.	Authority.
	Feet.	*Feet.*	
Cheboygan [a]	626	45	Taylor.
Hammonds Bay [a]	626	45	Do.
Rogers	621	40	Gregory.
Crawford's quarry	619	38	Do.
Thompson Harbor (storm bar)	(?) 635	54	Do.
Alpena [b]	613	32	Taylor.
Ossineke	(?) 614	33	Gregory.
Harrisville [a]	604	23	Taylor.
Greenbush [a]	603	22	Do.
Oscoda [a]	601	20	Do.
Tawas [a]	599	18	Do.
Alabaster [a]	599	18	Do.
Au Gres [a]	597	16	Do.
Kawkawlin [a]	595	14	Do.
St. Charles	597	16	Cooper.
Sebewaing [a]	597	16	Taylor.
Bayport [a]	596	15	Do.
Grindstone City [a]	598	17	Do.
White Rock [a]	595	14	Lane.
Port Huron [a]	595	14	Taylor.

[a] By hand level. [b] By aneroid barometer.

On the west side of Lake Michigan the Nipissing beach north of the hinge line was determined instrumentally at a number of places by Goldthwait and at a few on the Garden Peninsula by Hobbs. Some determinations were made by Russell and the writer by aneroid and hand level.

Altitudes of Nipissing beach on west side of Lake Michigan.

Locality.	Altitude above sea level.	Height above Lake Michigan.	Authority.
	Feet.	*Feet.*	
Rapid River	613	32	Hobbs.
Garden Bay	613	32	Do.
Burnt Bluff [a]	611	30	Russell.
Escanaba	609	28	Hobbs.
St. Martins Island	605	24	Do.
Washington Island	603	22	Goldthwait.
Detroit Harbor	602	21	Do.
Hedgehog Harbor	603	22	Do.
Ellisons Bay	602	21	Do.
Sister Bay	599	18	Do.
Ephraim	602	21	Do.
Fish Creek	602	21	Do.
Juddville	598	17	Do.
Egg Harbor	601	20	Do.
Baileys Harbor	602	21	Do.
Jacksonport	600	19	Do.
Graceport	600	19	Do.
Sturgeon Bay	598	17	Do.
Clay Banks	599	18	Do.
Algoma (4 miles north)	597	16	Do.

[a] By hand level.

The hinge line appears to be about at Algoma. South of this is the area of horizontality, in which measurements of the height of the Nipissing around the south end of Lake Michigan vary from 13 to 17 feet above the present lake level.

In Ontario the altitude of the Nipissing beach has been measured instrumentally by Goldthwait at numerous localities. One hand-level measurement by the writer is included.

Altitudes of Nipissing beach in Ontario.

Locality.	Altitude above sea level.	Height above Lake Huron.	Authority.
	Feet.	*Feet.*	
North Bay	698	117	Goldthwait.
Algoma Mills [a]	666	85	Taylor.
Coldwater	635	54	Goldthwait.
Wyebridge	637	56	Do.
Penetang	638	57	Do.
Collingwood	631	50	Do.
Thornbury	631	50	Do.
Meaford	629	48	Do.
Hogg	625	44	Do.
Presque Isle	625	44	Do.
Owen Sound	626	45	Do.
Wiarton	634	53	Do.
Hope Bay	635	54	Do.
Lions Head	636	55	Do.
Dyers Bay	640	59	Do
Southampton	617	36	Do.
Port Elgin	614	33	Do.
Inver Huron	608	27	Do.
Kincardine	600	19	Do.
Kettle Point [b]	596	15	Do.
Sarnia [b]	597	16	Do.

[a] By hand level. [b] In the area of horizontality.

On the south shore of Lake Superior the altitude of the Nipissing beach has been determined by hand level by Mr. Leverett and the writer as follows:

Altitudes of Nipissing beach on the south.

[By hand level except as indicated.]

Locality.	Altitude above sea level.	Height above Lake Superior.	Authority.
	Feet.	*Feet.*	
Sault Ste. Marie	651	51	Leverett.
Iroquois Point	645	45	Do.
Grand Marais	635	35	Do.
Munising	629	29	Do.
Marquette	628	28	Do.
L'Anse	620	20	Do.
Lac la Belle	635	35	Taylor.
Eagle Harbor	640	40	Do.
Copper Harbor	640	40	Leverett.
Houghton	626	26	Taylor.
Portage Canal, north end [a]	630	30	Do.
Ontonagon	616	16	Leverett.
Bayfield, Wis	606	6	Do.

[a] By aneroid.

On the north shore Lawson measured the altitude of the Nipissing instrumentally in many places, but did not recognize the beach from place to place. Nevertheless, by the characters which he described it is possible to identify it with a fair degree of accuracy at most of his localities.[1] The writer afterward visited a number of Lawson's localities and verified previous interpretations by further studies of the characteristics of the beaches between Fort William and Peninsula Harbor which had been judged to be the Nipissing.[2] The beach seems well identified at the following places, some of which were determined by Mr. Leverett in 1911:

Altitudes of Nipissing beach on north shore of Lake Superior.

Locality.	Altitude above sea level.	Height above Lake Superior.	Authority.
	Feet.	*Feet.*	
Beaver Point, ordinary beach [a]	606	6	Leverett.
Engles Cove, storm beach [a]	611.5	11.5	Do.
Cove near Baptism River, storm beach [a]	616	16	Do.
Kennedys Cove, ordinary beach [a]	609.5	9.5	Do.
Little Marais, ordinary beach [a]	612	12	Do.
Little Marais, storm beach [a]	618	18	Do.
Pork Bay, ordinary beach [a]	612	12	Do.
Thomasville, ordinary beach [a]	615	15	Do.
Thomasville, storm beach [a]	620	20	Do.
Cross River, ordinary beach [a]	618	18	Do.
Cross River, storm beach [a]	623	23	Do.
Lutzen by Poplar River, ordinary beach [a]	623.5	23.5	Do.
Lutzen, storm beach [a]	627.5-629	27.5-29	Do.
Carbou Point, ordinary beach [a]	622.5	22.5	Do.
Carbou Point, storm beach [a]	628	28	Do.
Good Harbor Bay, ordinary beach [a]	627	27	Do.
Grand Marais, ordinary beach [a]	630	30	Do.
Grand Marais, storm beach [a]	638	38	Do.
Red Cliff camp, ordinary beach [a]	634	34	Do.
Horseshoe Bay	639	39	Lawson.
Chicago Bay, ordinary beach [a]	638	38	Leverett.
Chicago Bay, storm beach [a]	644	44	Do.
Grand Portage	638	38	Lawson.
Mount Josephine	643	43	Do.
Wauswaugoning Bay	644	44	Do.
McKellars Point	648	48	Do.
Carp River	652	52	Do.
Pigeon Point	657	57	Do.
Port Arthur	661	61	Do.
Mazokama	698	98	Do.
Simpson Island	693	93	Do.
Terrace Bay	696	96	Do.
Jackfish Bay	703	103	Do.
Peninsula Harbor [b]	710	110	Taylor.

[a] By hand level. [b] By aneroid.

If rightly identified the altitude of the Nipissing beach is the same at Mazokama as at North Bay, and is therefore on the isobase at the former place. The nearest strand to the Nipissing

[1] Taylor, F. B., The Nipissing beach on the north Superior shore: Am. Geologist, vol. 15, 1895, pp. 304-314. This is a study of Lawson's results as set forth in his paper referred to above.

[2] Notes on the abandoned beaches of the north coast of Lake Superior: Am. Geologist, vol. 20, 1897, pp. 111-128.

at Nipigon, as indicated by the production of its plane from other places where it is better identified on this shore, is 8 or 10 feet lower than would be expected and lacks distinctive character. It is therefore rejected here, though given a probable place of identification in the review of Lawson's paper. Peninsula Harbor lies about 13 miles north of the isobase of North Bay, and the extreme reach of the lake waters northeastward from that line is 14 to 15 miles. The isobase runs about N. 65° W. to S. 65° E., and the tilt line or line of greatest rise therefore runs about N. 25° E.

POST-NIPISSING UPLIFTS OF NORTHERN LANDS.

From the northward rise of the Nipissing beach it appears that uplift of the northern lands did not cease with Lake Algonquin, but continued, though perhaps with less rapidity, for some time after the beginning of the Nipissing Great Lakes. It affected the lands bordering Lake

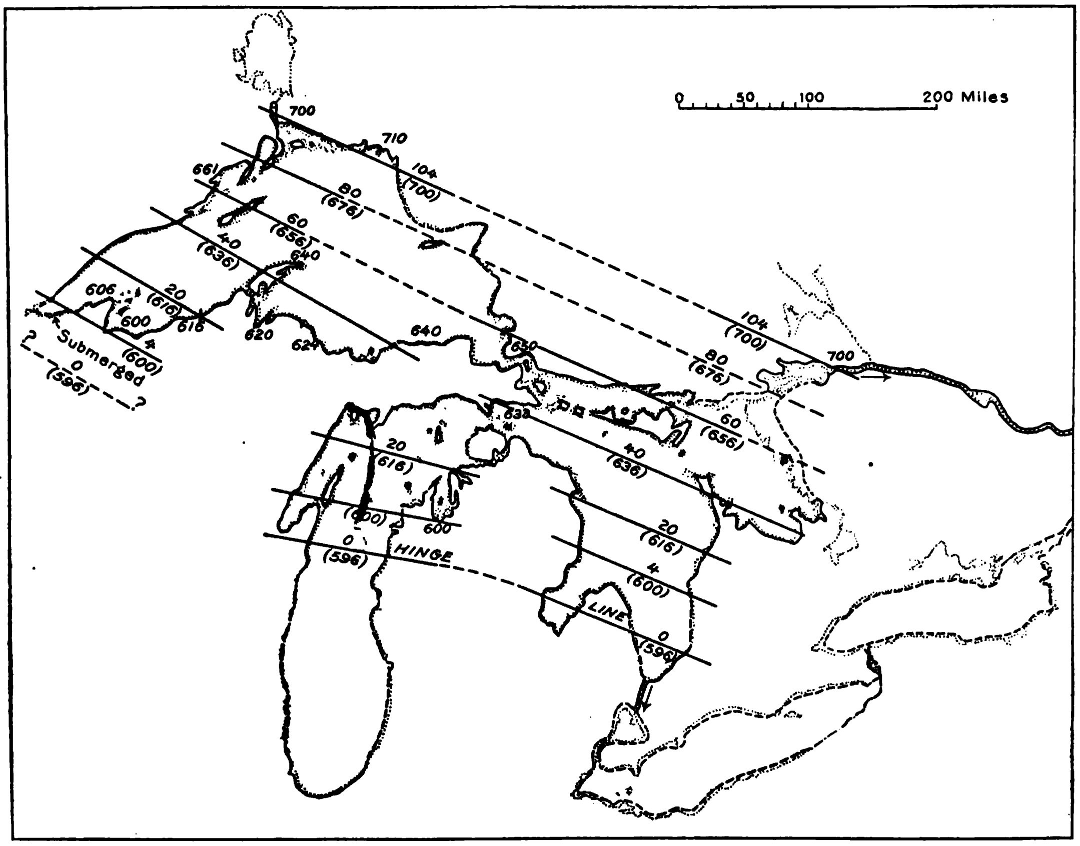


FIGURE 9.—Map of the isobases of the Nipissing Great Lakes at the two-outlet stage. The numbers above the isobases are altitudes above the horizontal or unaffected part of the beach south of the hinge line; the numbers in parentheses below the isobases are altitudes above sea level.

Superior, the northern third of Lake Michigan, and all of Georgian Bay and Lake Huron except Saginaw Bay and the south half of the south arm of Lake Huron. (See fig. 9.)

Goldthwait's measurements on the two sides of Lake Michigan seem to show that the hinge of the uplift that deformed the Nipissing beach is there on the same line as that which deformed the Algonquin beach. In the basin of Lake Huron this relation has not yet been so clearly made out and some doubt remains as to whether the hinge line of the Nipissing beach is not a few miles farther north than the Algonquin. In a small area at the west end of Lake Superior the plane of the Nipissing beach appears to pass below the level of the lake. In the basins of Lakes Michigan and Huron the Nipissing or two-outlet beach comes to an attitude of horizontality at about 596 feet above sea level. This level in the basin of Lake Superior is 4 or 5 feet below the water surface. Agreeing with this interpretation, Mr. Leverett found that the

plane of the Nipissing beach is only 6 feet above present lake surface 4 miles south of Bayfield and that, declining southwestward, it intersects the surface at the head of Ashland Bay. A line drawn from this intersection parallel with the isobases of the Nipissing beach (about N. 65° W.) intersects the north shore about 15 miles east of Duluth. (See also p. 456.)

The hinge line of the Algonquin beach at the west end of Lake Superior appears to be located at an undetermined distance south of Duluth and does not appear to fall within the basin of the lake unless the descent of the Algonquin plane southward is much more rapid than has been supposed. The south slope of the Lake Superior basin south of Duluth is largely covered with pebbleless lake clays which bear poor records of the beaches, showing only as wave-cut benches with low cliffs and narrow sloping terraces. For this reason, and on account of the forested condition of most of the country, the Algonquin beach has not yet been surely determined. If the beach runs westward from the region of the Keweenaw Peninsula without notable turning (and such northward bending is not suggested by the isobases of the beaches of Lake Duluth as determined by Mr. Leverett[1]) then the Algonquin beach 12 to 15 miles south of Duluth should have an altitude of something more than 700 feet above sea level or more than 100 feet above the lake, indicating a relatively wide separation of the hinge lines of the Algonquin and Nipissing beaches, amounting perhaps to as much as 100 miles.

A characteristic of the Nipissing beach is the remarkable evenness of its plane over the whole area over which it has been uplifted and tilted. Its variations from a true plane inclined slightly southwestward are, so far as now known, few and small. At North Bay the plane has been uplifted 102 to 104 feet from the horizontal and at Peninsula Harbor, at the extreme northeast angle of Lake Superior, 115 feet (aneroid); and the uplift has produced the effect of simple tilting of a rigid plane and with little irregularity or warping.

CORRELATIVES OF THE NIPISSING GREAT LAKES.

LAKE ST. CLAIR.

During the time of the Nipissing Great Lakes Lake St. Clair was at low stage; in fact, it was almost if not wholly abandoned as a lake. Only a sluggish, relatively small stream with locally expanded ponds or swampy parts remained. (See p. 496.)

LAKE ERIE.

The height of the water in a lake is in some degree dependent upon the volume of discharge at its outlet, especially where the variation of volume is as great as 700 per cent. (See p. 496.) The effect is also largely dependent upon the shape of the outlet; if this is broad and shallow the effects of variation in volume will be slight, but if it is deep and narrow they will be relatively large. Where Niagara River passes over the ledges of the Onondaga limestone at Black Rock, its channel contains a narrow and rather deep passage which probably carried the whole of the stream at the low stages, and this resulted in a lowering of the lake level more than if the rock sill had been broad and even. Lake Erie alone furnishes about 15 per cent (nearly one-seventh) of the whole volume of Niagara River, and the conditions on the sill at the outlet are such that a variation of 700 per cent in volume would markedly affect the level of the lake. This variation is therefore, in all probability, the chief explanation of the drowning which Moseley[2] found at Sandusky, Ohio, and on the islands in Lake Erie. He describes an old land surface with stumps of trees and other vegetable remains now submerged 10 to 12 feet, and also narrow creek beds which are sharply trenched into the bottom of Sandusky Bay and are traceable across its whole width.

Thus Lake Erie was at low stage during all the time of the Nipissing Great Lakes, and if, as seems certain, the Fort Erie beach had been made previously (during the time of Lake Algonquin) with the waters at high stage, then the outlet, with the level of the lake at low stage, was

[1] Outline of history of the Great Lakes: Twelfth Rept. Michigan Acad. Sci., 1910, map on p. 27.

[2] Moseley, E. L., Lake Erie enlarging; the islands separated from the mainland in recent times: Lakeside Magazine, Lakeside, Ohio, vol. 1, 1898. pp. 14-17. Also Formation of Sandusky Bay and Cedar Point: Proc. Ohio State Acad. Sci., vol. 4, 1904, pt. 5, pp. 179-238.

probably not less than 10 or 15 feet below the Fort Erie beach. This beach is now 13 or 14 feet above lake level at Fort Erie. It declines in altitude very gradually westward, but the nodal point where it passes below lake level is not yet known. The lake is now at high stage and Moseley's submerged land, drowned 10 to 12 feet, is almost certainly the low-stage correlative of the Nipissing beach in the upper lakes. If this be true, no recent uplift of the land at Buffalo is required to explain the amount of drowning which Moseley finds around the west end of the lake, but only a change from the low stage during the Nipissing Great Lakes to the present high stage. The status of the Fort Erie beach in the west end of the lake has not yet been determined. It seems probable that it is somewhat lower than the recent low-stage beach of Lake Erie, though the relation of the earlier beaches to the Algonquin and earlier hinge lines (pp. 442–443) indicates that it is probably not more than 10 to 15 feet lower.

It was stated above (p. 442) that after Lake Erie had become an independent nonglacial lake it had three stages, the third ending with the end of Lake Algonquin. Later, it had a fourth stage, which resulted from the opening of the outlet at North Bay, Ontario, by the retreat of the ice sheet. This took the whole discharge of the upper lakes away from Lake Erie and established its second low stage, which was 10 to 12 feet lower than present lake level and which lasted throughout the time of the Nipissing Great Lakes.

CHAMPLAIN SEA.

The channel of the Algonquin outlet river appears to descend to or possibly below present lake level at Trenton. (See p. 444.) This river ceased to flow when the Kirkfield outlet was abandoned, and the northward splitting of the Algonquin beaches shows that the greater part of the uplift occurred not long after this event, or during the Port Huron-Chicago stage of Lake Algonquin. Thus, if the Algonquin River is rightly interpreted as extending to Trenton, Lake Iroquois, Lake Frontenac, and Gilbert Gulf seem to have disappeared before the beginning of the Nipissing Great Lakes, and the greater part of the elevation of the land at Prescott and Trenton, Ontario, occurred before that time. Indeed, it is not certain but that the Champlain Sea had nearly disappeared and all the uplift, except perhaps about 20 feet, had been accomplished. It seems probable that the marine correlative of the Nipissing beach of the upper Great Lakes is not far above present sea level and might be looked for along the lower tidal St. Lawrence.

Goldthwait[2] found a heavily developed shore line, which he calls the Micmac beach, extending for 200 miles below Quebec along the south side of the lower St. Lawrence. In 1912 this beach was seen by the writer at many points on the north side between Quebec and Tadousac. It is strong and continuous between Quebec and Ste. Anne de Beaupre. It is 20 feet above the level of the Gulf of St. Lawrence and is horizontal so far as seen. Wave action at this level was evidently powerful and prolonged, for the sea cliff is in places 100 feet high, cut in shale, and the wave-cut bench is everywhere unusually wide. The Micmac beach resembles nothing in the Great Lakes region so much as the Nipissing beach, but its actual correlative in the lakes region is not yet known. Further studies in the field will be necessary before the later marine shore lines of the St. Lawrence Valley can be safely correlated with beaches in the region of the Great Lakes.

[2] Goldthwait, J. W., The 20-foot terrace and sea cliff of the lower St. Lawrence: Bull. Geol. Soc. America, vol. 22, 1911. pp. 723–724.

CHAPTER XXIII.

POST-NIPISSING GREAT LAKES AND SUMMARY OF GLACIAL AND NONGLACIAL LAKES.

By FRANK B. TAYLOR.

POST-NIPISSING GREAT LAKES.

POST-NIPISSING BEACHES.

The Nipissing beach of the two-outlet stage was the last shore line of the Nipissing Great Lakes. It was a transition beach, and when the discharge of the upper lakes abandoned North Bay entirely and had returned to Port Huron the Nipissing Great Lakes as here defined ceased to exist and the post-Nipissing or present stage of the upper lakes was inaugurated. Since that time there has been no change of outlet, but only a slow uplift in the north and a gradual lowering by erosion of the outlet. There was probably at first a very small overflow at Chicago, but it soon ceased as St. Clair River deepened its channel. The whole deepening since the time of the Nipissing beach has lowered Lakes Michigan and Huron 11 or 12 feet, and by the time the lowering had reached 3 or 4 feet the discharge at Chicago had ceased entirely.

The existence of beaches later than the Nipissing is due to the continuance of differential uplift, by which the Nipissing beach at North Bay has been raised to an altitude of 698 or 700 feet, while in the area of horizontality it has remained at an average altitude of about 596 feet. Thus, since the upper lakes attained their present arrangement the uplift of the land at North Bay has amounted to 102 to 104 feet, and it is to be remembered that while this amount of uplift was going on in the north, Lakes Huron and Michigan south of the hinge line were lowered by erosion 11 or 12 feet, allowing 3 feet for the height of the beach above the water.

For some distance north of the hinge line the beaches due to this uplift are not well displayed, being compactly set over the whole slope below the Nipissing beach, and being therefore difficult to recognize individually for more than a short distance. Farther north, at Mackinac Island, however, the uplift has been 38 or 39 feet, and the beaches begin to be distinctly separated. Still farther north they are still more distinct, especially near Sault Ste. Marie and along the north channel of Lake Huron.

At present, however, the data accumulated do not warrant any detailed description of these beaches. In fact, nearly all of them are of about the same strength, and none offers any certain clue by which it can be followed and identified from place to place. Nevertheless, in all probability, careful study of these youngest raised beaches would yield results of great value in the study of the most recent earth movements that have affected the Great Lakes region.

Among the beaches below the Nipissing is the Algoma, which has been somewhat doubtfully identified at many localities. It was first observed by the writer at Algoma Mills on the north channel of Lake Huron in 1893. At that place its altitude by aneroid was made about 630 feet or about 50 feet above Lake Huron. This beach is probably represented at Sault Ste. Marie by a beach at 620 feet, observed by Mr. Leverett. At Mackinac Island a beach which seems to correspond to this has an altitude of 605 feet, and at a number of places farther south it seems to be satisfactorily identified. Hobbs reports a beach corresponding to the Algoma at 599 feet at Clamshell Harbor, on the Garden Peninsula, northern Michigan. In the area of horizontality a beach among the several light ridges below the Nipissing and having an altitude of 591 to 592 feet (10 or 11 feet above the lake) is generally a little stronger than the rest and is regarded as the Algoma beach. The only basis of its identification, however, is the fact that it is a trifle stronger than the others above and below it.

A beach below the Nipissing and bearing about the same relation to it as the Algoma beach in the Lake Huron basin was found by the writer in 1895 at a few places on the north shore of Lake Superior.[1] It was thought at the time that this beach hinged on the outlet at Sault Ste. Marie and that it marked the first establishment of that outlet and its isobase as the controlling or nodal line for the tilting in that basin. For this reason the beach was called the Sault beach. This correlation, however, now seems somewhat uncertain, because all the points where the beach was observed are on the north shore far away from Sault Ste. Marie, where Mr. Leverett has since found the Algoma beach at an altitude of 620 feet, or only 20 feet above the level of Lake Superior. It seems not improbable, therefore, that the shore line which the writer called the Sault beach is in fact the Algoma beach extending through a narrow strait into the basin of Lake Superior. If it were permissible to suppose that the sill at Sault Ste. Marie has been cut down 20 feet since it first became functional, it would at first have held the water at about the level of the Sault beach. The coincidence of the two beach planes would then be accidental. It does not seem probable, however, that Lake Superior could have been held 20 feet above its present level for any length of time by the barrier of drift at Sault Ste. Marie. The present barrier is of bedrock and affords no evidence of having been perceptibly lowered by the river in postglacial time. The drift that rested on the bedrock must have been quickly removed, and it seems probable, therefore, that the Sault beach is in reality identical with the Algoma.

LAKE ERIE.

At the beginning of the present lake stage Lake Erie had become an independent body and had passed through four stages. At the beginning of the present stage renewed uplift of northern lands had raised North Bay, closed the outlet at that place, and brought the Nipissing Great Lakes to an end. This sent the whole discharge of the upper lakes back to Port Huron and Lake Erie, gave Lake Erie a large-volume discharge at Buffalo, and established its fifth stage (third high stage). The uplift which produced this change had little or no effect at Buffalo and probably produced no drowning in the western part of the lake, for its hinge line appears to have passed a little to the north of the outlet.

Through all the changes that have affected Lake Erie since it became an independent body the rock sill at Buffalo has lowered not more than 10 feet. This lowering was probably accomplished mainly during the two low stages, which lasted longer than the high stages and made more effective attacks on the sill, for during the high stages the volume of water was so great that the stream glided over the sill as a smooth rapids, whereas at the low stages a low cascade or waterfall came into being and attacked the rock ledge more effectively. The narrow, deep channel through the ledge was probably made in this way. The crest of the Fort Erie beach ridge, which marks the first stage (a high stage) of Lake Erie after its separation from Lake Ontario, is now 13 to 14 feet above the lake at Fort Erie, Ontario. Assuming the average height of the beach ridge to have been 3 or 4 feet above the water surface and storm beaches somewhat higher, it is evident that the lake level at the outlet has lowered not more than 10 feet since the time of separation.

RECENT UPLIFT AND PRESENT STABILITY OF THE LAND.

GENERAL EVIDENCES OF PROGRESSING OR VERY RECENT UPLIFT.

It used to be thought that the uplifts which have deformed the old water planes of the Great Lakes progressed at a substantially uniform rate and hence were distributed more or less evenly throughout the whole existence of the lakes. This conclusion, however, is not justified by the facts now known. Although some slight uplift took place before the time of Lake Algonquin, the great movement did not begin until a short time before the abandonment of the Kirkfield outlet. Its greatest activity was during the construction of the Battlefield beaches, for

[1] Notes on the abandoned beaches of the north coast of Lake Superior: Am. Geologist, vol. 20, 1897, p. 127.

most of these are rather weak and are separated by wider barren or only faintly wave-washed vertical intervals than are those of any other group. The movement of elevation was much slower during the making of the upper group of Algonquin beaches, and it was also slower during the making of the Fort Brady group. It seems again to have been very much slower, if indeed it did not entirely cease for a time, during the making of the original Nipissing and the Nipissing two-outlet beaches. It was slow also after the time of the two-outlet Nipissing beach.

Judgment as to the rate of recent or progressing uplift, however, depends much on the place of observation. At Mackinac Island and farther south recent close-set, well-developed beaches give the impression that the uplift was very slow and that the beaches had a long time to form. But on the north shore of Lake Superior the beaches below the Nipissing are not well developed and might be supposed to indicate that the land rose too rapidly for the making of beaches of any strength. Locally, however, this is due largely to poor supply of materials. The Nipissing beach itself is well developed only in recesses of the rocky shore, for the hard rocks of this coast were not much affected by the waves and many stretches were bare of drift.

It has been assumed by some that uplift has gone on in recent times at a substantially uniform rate and that it is still progressing. The spasmodic movements in the past cast some doubt on this assumption, although it is of course possible that both spasmodic and slow movements took place. On the other hand, the unbroken series of rather light beach ridges between the Nipissing beach and the present shore seems to show very recent and possibly still continuing uplift in the northern part of the basins. There are some reasons, however, for believing that uplift of the land is not now in progress and has not been for at least 100 or 200 years. If differential uplift, like that which tilted the Nipissing beach, is now in progress it would affect the north sides of the lake basins most and would die out at the hinge line.

Indirect effects, however, would tend to extend over the area south of the hinge line, for those lakes which have their outlets located north of the hinge would have their waters backed up on their southern shores. If the outlets were near the hinge line the uplift would be slight and the drowning effects might be negligible, but at distances of 100 to 200 miles north the effects, if uplift is now in progress, ought to be perceptible in a few centuries, even if not certainly measureable in 50 or 60 years. It is significant that some of the strongest evidences suggesting progressing or very recent uplift have been found on the northerly shores, most notably at the mouth and on the lower course of Nipigon River and of certain streams on the north shore of Lake Huron.[1] These evidences seem to show very recent or progressing emergence of the land, but, like the indirect evidences derived from the drowning of southwestern shores, they give no definite time relations nor rates of uplift. It should be noted that the distribution and character of possible recent and progressing uplifts in this region are distinctly limited, for the uniformity of the tilted water plane marked by the Nipissing beach shows conclusively the absence of notable warping or locally restricted uplifts; if any measurable movement has occurred recently or is now in progress it must be of the character of widespread tilting, affecting as a unit an extensive area north of the hinge line.

Indirect evidence derived from features indicating recent or progressing drowning of southwestern shores is more ample in amount but perhaps less definite in its significance. Great barrier bars and spits like Minnesota Point, at Duluth, Minn.; Chaquamegon Point, near Ashland, Wis.; Cedar Point, near Sandusky, Ohio; the point at Rondeau, Ontario; Presque Isle, at Erie, Pa.; Long Point, at Port Rowan, Ontario; Burlington Beach, near Hamilton, Ontario; and Toronto Island, at Toronto, Ontario, seem surely to indicate either relative permanence of water level or only very slow drowning. The bars at Duluth, Sandusky, Rondeau, Erie, and Port Rowan are in the area of horizontality for the later uplifts, but those near Ashland, Hamilton, and Toronto are north of the hinge line but not far from it, Toronto being the farthest at a distance of about 60 miles. All of these places would be subjected to drowning by northern uplifts affecting the outlets of the lakes in which they occur, and it is a notable fact that all of the great bars mentioned are on those lakes which have northerly outlets. The outlet of Lake Erie proba-

[1] Taylor, F. B., Notes on the abandoned beaches of the north coast of Lake Superior: Am. Geologist, vol. 20, 1897, pp. 120-122.

bly lies near the hinge line of the most recent uplifts, but the position of the line in that region is not definitely known. The outlets of Lakes Superior and Ontario are well within the area of the recent uplifts.

Lake Michigan-Huron (regarded as one lake) has its outlet toward the south in the area of horizontality, and for this reason the northern uplifts have not backed the waters up on its southern shores. Since the end of the Nipissing Great Lakes the water level south of the hinge line in this lake has been permanent, except for lowering due to wearing down of the outlet. The recent uplifts merely raised the northern shores and caused them to emerge without producing drowning at the south. During the early part of the present post-Nipissing lake stage Lake Superior and Lake Michigan-Huron were united by a strait and had the same southern outlet. About 50 feet of uplift occurred at Sault Ste. Marie while this relation lasted. It is only during the last 20 feet of uplift at Sault Ste. Marie that Lake Superior has been an independent lake and has had its outlet in the area of uplift north of the hinge line. The emergence effects on the lower Nipigon are due to the latest movement, whether now progressing or only of recent date.

On theoretical grounds it seems certain that very slow drowning would favor the growth of great barriers and spits like those mentioned, for it would greatly facilitate the erosion of all exposed shores and enormously augment the supply of beach-making material. But so also would a rise of lake level due to increased volume of discharge, like that which affected Lakes Erie and Ontario at the beginning of the present lake stage, and this might be accompanied by no warping or uplifting whatever. In this case there would be sudden drowning of small amount (10 or 12 feet) and a permanent lake level thereafter. Reasons have already been given (p. 465) for believing that Lake Erie was not appreciably affected by the post-Nipissing uplifts. The last drowning that affected it was due to increased volume and rise of lake level following a long low stage. The modern great bars of Lake Erie seem therefore to be due to relatively long permanence of lake level following a sudden rise of small amount.

The spits on the shore of Lake Ontario seem to indicate the same general conditions of formation as those of Lake Erie, both in distribution and in strength of development (including duration of time involved). It seems impossible to reconcile the great spits at Toronto and Hamilton with an uplift of appreciable rate now in progress or with a very recent uplift of more than 10 or 15 feet. It seems more probable that a large increase in the volume of discharge without concurrent or subsequent uplifting of the land has been the chief factor. In this connection it should be noted that the extent of the post-Nipissing uplift east of Lake Huron and Georgian Bay has not yet been determined by observation. It seems almost certain, however, that the isobases bend gradually to the east in southwestern Ontario so as to leave the outlet of Lake Erie at or south of the hinge line, and it is a question whether in passing farther eastward they do not curve still more, turning to courses somewhat north of east, so as to leave the outlet of Lake Ontario likewise at or near the hinge line. In this case the outlet of Lake Ontario may have been affected little if any by the post-Nipissing uplift and the spits of this lake may also be due to a rise in lake level caused by increased volume of discharge.

From the Niagara gorge it is learned that the whole of the post-Nipissing uplift, amounting to about 104 feet at North Bay, Ontario, has taken place in the last 3,000 or 3,500 years. It seems probable that the greater part of it occurred in the early part of this period and very little in the last few hundred years, but the facts now available do not appear to afford a satisfactory basis for determining whether uplift is now in progress and what its rate is if it is going on.

GAGE READINGS AND PROGRESSING UPLIFT.

Some years ago Gilbert investigated the question of progressing uplift by collecting and critically examining and comparing the records of changes of lake level at selected points where gages have been kept by the United States Lake Survey.[1] The result showed a very small

[1] Gilbert, G. K., Modification of the Great Lakes by earth movement: Nat. Geog. Mag., vol. 8, 1897, pp. 233-247. Also more fully in Recent earth movement in the Great Lakes region: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1897, pp. 595-647.

differential elevation or tilting for several of the more northerly stations as compared with stations farther south. The mean result on the assumptions made indicates an uplift of 0.42 foot per 100 miles in a century on a line running N. 27° E.

The stations chosen were Milwaukee and Escanaba on Lake Michigan, Port Austin on Lake Huron, Cleveland and Port Colborne on Lake Erie, and Charlotte and Sacketts Harbor on Lake Ontario.

Unfortunately, when Gilbert finished his investigations (1896) the position and attitude of the Nipissing plane in the southern parts of the basins of Lakes Huron and Michigan had not been correctly determined. It was then supposed that both the Algonquin and Nipissing beaches passed under the present lake level southward, the Nipissing being about 20 feet beneath it at Port Huron and about 100 feet beneath it at Chicago. These, however, were estimates based chiefly on the planes of the beaches produced from the north and partly on erroneous determinations of the places where the planes cut the lake surface. The responsibility for these errors is shared by Spencer and the writer.

Since that time it has been found that, instead of passing under the lake surface southward both beaches become horizontal, the Algonquin at about 25 feet above the present lake level and the Nipissing at about 15 feet. The hinge lines, where the planes pass from an inclined to a horizontal attitude, are thought to be very nearly coincident across the southern peninsula of Michigan. (See fig. 8, p. 439, and fig. 9, p. 461.)

These newly found facts throw fresh light on the problem of recent earth movement in the Great Lakes region, introducing important changes in Gilbert's assumptions and modifying his interpretation of some of the data. The relations of his chosen stations to the area of horizontality becomes a matter of much importance. Of these, Chicago and Cleveland are far within the area of horizontality in which no recent earth movement is known. Port Austin and Port Colborne are both close to the hinge line of latest uplift and may be on it or slightly south of it; at most they are not far north of it and have been affected very little by recent uplifts. Only Escanaba, Charlotte, and Sacketts Harbor are well within the area of uplift. Of the four pairs of stations considered only the pair on Lake Ontario is wholly within the deformed region. This makes it necessary to modify Gilbert's result for three of the pairs, and leaves it unchanged for only one—Charlotte and Sacketts Harbor.

If the movement indicated between Milwaukee and Escanaba is really caused by uplift at Escanaba, its rate is more than twice that obtained by Gilbert, if his determination is numerically accurate, for the hinge line of the movement is probably more than halfway north from Milwaukee to Escanaba. The last movement recorded by the beaches appears to have hinged on this line.

It seems doubtful whether Gilbert's investigation proves that uplift of the land is now in progress. But, on the other hand, a demonstration that Gilbert's conclusions are not well founded does not constitute proof of the truth of the contrary proposition, namely, that uplift of the land is not now in progress. The author is inclined to the belief that the movements of uplift are spasmodic in character and occur rather suddenly at intervals separated by long periods of rest, during which movements do not occur. It may be doubted whether a measurable movement of uplift has occurred within the last 100 or 150 years. The old beaches in many places suggest sudden uplift, and the place in the Niagara gorge which marks the last increase of volume (just above the railroad bridges) shows a change in gorge characters so abrupt as to be consistent only with a relatively sudden great increase of volume. This change was due to uplift at North Bay, Ontario, closing the outlet there and sending the discharge back to Niagara.

The lack of water-gage stations on the northern shores, especially on those of Georgian Bay and Lake Superior, seems to necessitate postponement of further efforts to solve this problem by this method until observations shall have been collected for many years from stations that still remain to be established. The need of such stations is urgent and immediate. The most desirable places are at the mouth of French River at the north end of Georgian Bay, and at Peninsula Harbor at the extreme northeast angle of Lake Superior. Stations at these two places would afford the longest possible lines in the direction of recent tilting.

SUMMARY OF GLACIAL AND NONGLACIAL LAKES IN THE HURON-ERIE AND MICHIGAN BASINS.

The table below presents a condensed summary of information concerning the Huron-Erie and Michigan glacial lakes and the nonglacial lakes that followed in the same basins.

Glacial and nonglacial lakes of the Huron-Erie and Michigan basins.

	Lake names.	Number of stages.	Beach names.	Elevation of beach (south of hinge).	Location of ice dam.	Place of outlet.	Remarks.
Glacial Lake Chicago. (Data given at bottom of table.)	Maumee.	Three.	Highest (first).	*Feet.* 800–805	Defiance and Birmingham moraines.	Fort Wayne channel.	Discharge at Fort Wayne during middle beach was small and temporary. The lowest beach was drowned during making of the middle beach. Outlet for lowest overridden.
			Middle.	775–785	Imlay to Yale moraine.	Imlay channel (and Fort Wayne ?).	
			Lowest.	760±	?	Near Imlay (?).	
	Arkona (and Saginaw basin).	Three.	First Second Third	708–710 698–702 690–694	About 25 miles northeast of Bad Axe and same distance north of Alden, N. Y.	Grand River channel.	Except where protected in Black River valley, beaches submerged and destroyed during Lake Whittlesey; overridden on "thumb;" not submerged in Saginaw Valley. Only two west from Flushing.
	Whittlesey.	Two.	Whittlesey (Belmore). Beach "A"	735–740 ?	Port Huron moraine.	Ubly channel.	During the time of Lakes Maumee and Whittlesey Lake Saginaw was a separate lake.
	Wayne (and Saginaw basin).	One.	Wayne (Lower Forest).	650–657	? Nearly same as for Lake Arkona.	Near (south of) Syracuse, N. Y.	Beach submerged during Lake Warren.
	Warren (and Saginaw basin).	One.	Warren (Forest).	675–680	A little west of Alpena, Mich., and Niagara Falls moraine.	Grand River channel.	The Wayne and Warren beaches were upwarped on the "thumb" during the life of Lake Lundy.
	Lundy (and Saginaw basin).	Two.	Grassmere.	635–640	A little farther north than for Lake Warren.	Near (south of) Syracuse, N. Y.	The Grassmere and Lundy beaches show remarkable splittings northward in Sanilac and Huron counties, Mich.
			Lundy (Elkton or Dana).	615–620			
	Algonquin.	Many, divided into four groups.	(1) Beach of Early Lake Algonquin; theoretical; not yet distinguished.	?	? About at Alpena, Mich., and Port Elgin, Ontario.	Port Huron.	Early Lake Algonquin was confined to south half of Lake Huron, with tributary lakes from east. Main lake covered three upper basins. Upper group possibly absent in north part of Huron and Superior basins. Most rapid uplift during construction of Battlefield group. Beaches in Lakes St. Clair and Rouge basins are correlatives of the Algonquin and Nipissing, not identical.
			(2) Main upper Algonquin group.	603–607	Several positions between Alpena and Mattawa Valley.	Kirkfield, Ontario; later at Port Huron and Chicago.	
			(3) Battlefield beach and group.	? Main ridge 714 feet on Mackinac Island.	In Mattawa Valley (?).	Port Huron (and Chicago ?).	
			(4) Fort Brady beaches and group.	? (640–690 feet on Mackinac Island).	In Ottawa Valley (?).	Port Huron (and Chicago ?).	
	Nipissing.	Two.	Original Nipissing. Nipissing (two-outlet stage).	530± 594–597	None None	North Bay, Ontario. North Bay and Port Huron.	The original Nipissing beach (theoretical) is now all submerged south of isobase of North Bay. The well-known Nipissing beach marks a later two-outlet stage.
	Post-Nipissing Great Lakes.	Many.	Algoma.	589–591	None.	Port Huron.	Lies a little above the middle of the series below the Nipissing.
	(Chicago).[1]	Three.	Glenwood Calumet Toleston	640 620 607	Retreating positions in Lake Michigan basin.	Chicago.	Correlative of Lake Maumee to Early Lake Algonquin, inclusive. Probably joined with waters of Lake Superior before those of Huron.

[1] The chronological place of Lake Chicago is shown above.

CHAPTER XXIV.

POSTGLACIAL DEVELOPMENT OF CONNECTING RIVERS OF THE GREAT LAKES.

By Frank B. Taylor.

RELATIONS OF RIVERS.

At its maximum extent the last ice sheet covered not only all the Great Lake basins, but also the sites of all the rivers which now connect the lakes with each other and with the sea. Special interest attaches to the development of these connecting rivers, not only because of the intimate relation between their histories and lake history in general, but also because of the processes and stages of development which they show and the remarkable youth or newness which characterizes their beds.

The Great Lake basins are certainly very old and were probably more or less connected by channels in preglacial times. But the vicissitudes of several successive glacial invasions, the lake and river developments of the intervening warm periods, and the differential uplifts which have affected the land have probably obliterated and reestablished the main connecting channels several times over. What is said here relates only to the reestablishment since the obliteration caused by the last ice sheet.

Of all the different facts that show the relative recentness of the postglacial changes which have brought the Great Lakes to their present state none perhaps are so clear and convincing as those pertaining to the rivers which connect the basins. Nipigon River is sometimes called the upper St. Lawrence from the fact that it is much the largest tributary of Lake Superior. In the same sense all the connecting rivers—St. Marys, St. Clair, Detroit, and Niagara—are parts of the St. Lawrence system. The St. Lawrence proper, connecting Lake Ontario with the sea, should be included in any comprehensive view of the development of this river system, for it has had the same general history as the other parts and displays the same striking evidences of newness.

However, only St. Clair and Detroit rivers lie within the region discussed, and only these will be considered in detail. The St. Clair and the Detroit are the oldest of the system; then come the Niagara, the Nipigon, the St. Lawrence, and the St. Marys. The relative ages of the Nipigon and the St. Lawrence are not certainly made out, but their beginnings were probably not far apart in time. The Niagara was distinctly earlier than either of these and the St. Marys was distinctly later. The different lake stages and the separation of the different links of this river system by the intervening lake bodies set uncommonly sharp limits to the beginning and duration of the different links.

EARLY INVESTIGATIONS.

The literature bearing particularly on St. Clair and Detroit rivers and Lake St. Clair, which alone lie within the field covered by this monograph, is not extensive. Much has been written about Niagara River, especially about Niagara Falls and the gorge, but this is outside of the range of the present inquiry.[1]

In one or two of his earlier papers Spencer speaks of the waters which preceded the Great Lakes as "lakes," and he found the outlet of one stage to be "southeast of Georgian Bay by way of the Trent Valley to Lake Ontario." At that time he attributed the change of outlet to the later uplifting of the Trent region, whereby the overflow passed southward to Lake

[1] The development and history of Niagara River and the Falls are discussed in Niagara folio (No. 190), Geol. Atlas U. S., U. S. Geol. Survey, 1913.

Erie. He called the outlet river in the Trent Valley the Algonquin River.[1] He was the first to trace the Iroquois and Algonquin beaches for long distances and to measure accurately their northward rise. In his later papers, however, he abandons these views and interpretations and appears to regard all the ancestral waters of the Great Lakes as marine with open connection with the sea. He combats the idea of continental ice sheets and ice dams and rejects all of the earlier glacial lake outlets, although he was first to describe two of them—the Trent River outlet at Kirkfield, Ontario, and the Imlay channel in Michigan—attributing the first discharge from Lake Huron to Lake Erie to the uplifting of the land in the region of Lake Nipissing northeast of Georgian Bay, and admitting no earlier activity for the Port Huron outlet. In 1891 Spencer rejected the Mohawk River outlet for Lake Iroquois and the Trent River outlet for Lake Algonquin and calculated the Algonquin beach to pass 20 feet below the present lake level at Port Huron, thus allowing for no southward outlet of Lake Algonquin at that place, nor for any eastward outlet at Kirkfield.[2] In 1894 he reaffirmed that the first discharge of the upper lakes southward to Lake Erie was due to uplift at Lake Nipissing.[3] In the first publication of his papers he repeatedly used the word "lake" in designating these early waters, but in a reprint in book form in 1895 he generally substituted the word "gulf."[4] In this volume he reaffirms his rejection of the Mohawk and Trent Valley outlets, the assumed submergence of the Algonquin beach at Port Huron, and the recent first opening of the southward outlet.

In a recent, more elaborate volume[5] he repeats the same views respecting the southward outlet for Lake Algonquin, although more than 10 years had intervened since his last publication on that subject and the investigations of others had in the meantime brought out new facts that point clearly to a different history. His earlier conjecture that the Algonquin beach passes 20 feet under Lake Huron at its south end was disproved in 1896 by the finding of the beach strongly developed 25 feet above the lake at Port Huron and Sarnia. But although he recognizes this fact in his recent report, Spencer reaffirms his belief that Lake Algonquin had no southward outlet.[6]

In the same work he discusses St. Clair River and the delta and puts forth views that are novel and in harmony with his hypotheses of Lake Algonquin and Niagara Falls, but not in accord with either the lake history or the features of the connecting river district as set forth in this monograph. He makes the first river in the St. Clair Valley a local stream—necessarily relatively small—and flowing northward. He makes it rise in the south part of the bed of Lake St. Clair, the many tributaries uniting at Algonac and flowing northward to Lake Algonquin, the shore of which, he says, was then 17 miles north of Point Edward and 110 feet below the present level of Lake Huron, or 90 feet deeper than by his earlier estimate. On the elevation of the land at Lake Nipissing, Ontario, he says the discharge of Lake Huron shifted south and for the first time passed to Lake Erie. The coming of the great river in a reverse direction into the bed of the previous small local river caused the drowning of the tributaries of St. Clair River.[7] (See, further, pp. 499–500.)

In discussing the relations between Niagara Falls and the upper Great Lakes, the fact that these lakes had two periods during which they discharged their overflow eastward was first distinctly recognized by Gilbert[8] in 1889, when he showed two hypothetical maps intended to represent the conditions at these periods. He states that during both periods the discharge of the upper lakes abandoned the southward course through St. Clair and Detroit rivers which it had previously taken and that these rivers ran dry. He states also that the gradual uplifting

[1] Spencer, J. W., Notes on the origin and history of the Great Lakes of North America: Proc. Am. Assoc. Adv. Sci., vol. 37, 1888, pp. 198-199.
[2] Deformation of the Algonquin beach and birth of Lake Huron: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 18, 19.
[3] Duration of Niagara Falls: Am. Jour. Sci., 3d ser., vol. 48, 1894, pp. 463, 466.
[4] The duration of Niagara Falls, Humboldt Pub. Co., New York, 1895, pp. 69-71, 73, 108, 111.
[5] Evolution of Niagara Falls, Geol. Survey Canada, 1907, pp. xxxi, 490.
[6] Idem, pp. 299, 303.
[7] Since this monograph was written, Spencer claims to have changed his views, accepting the idea of the land ice sheet and its function as a dam retaining lakes of great extent. But on the Niagara excursion connected with the Twelfth International Geological Congress at Toronto in August, 1913, he ignored the land ice sheet and reaffirmed the explanations given in his report of 1907. The intimate connection between the history of Niagara and the history of the Great Lakes as presented in this monograph is set forth briefly in the Niagara folio (No. 190, Geol. Atlas U. S., U. S. Geol. Survey, 1913).
[8] Gilbert, G. K., The history of the Niagara River: Sixth Ann. Rept. Commissioners State Reservation at Niagara, 1890, pp. 72-73, Pls IV, V.

of the land at the north caused the discharge of the upper lakes to shift from northerly to more southerly passes, thus implying a reestablishment of the full volume of discharge southward through St. Clair and Detroit rivers.

Gilbert does not go into the details of the history of the connecting rivers in his paper, but the abandonment and reoccupation which he describes were important factors in the development of these great river beds. In a later paper [1] he discusses the Great Lakes history in much the same way, without going into details relative to the other connecting rivers. In an article on recent earth movements in the Great Lakes region,[2] he recognizes the "drowned" character of the lower stream courses around Lakes Ontario and Erie, the southern half of Lake Michigan, and the south side of Lake Superior and attributes it to recent tilting of the land. The connecting rivers seem obviously included, but are not particularly mentioned.

In 1903 Cole [3] made a special study, under the direction of the Michigan State Geological Survey, of the delta of St. Clair River.

In his report on the geology of Monroe County, Mich., Sherzer discusses very briefly some rather exceptional till ridges in Monguagon and Brownstown townships, in Wayne County.[4] These ridges are separated by very well defined and persistent troughs, but Sherzer gives the ridges first importance, regarding them as parts of a moraine which he calls the Detroit moraine, and assigning no unusual quality or origin to the troughs. He gives a good description of the recent drowning of the shores of Lake Erie along the border of Monroe County, but does not discuss the distributaries of the Trenton district, which lie outside of that county.

In two papers published early in 1895 the writer [5] attempted to give the main outlines of the Great Lake history on the hypothesis of marine invasion of the upper three lakes and marine origin for some of the higher beaches of that region. Glacial lakes retained by ice dams were supposed to account for nearly all the beaches in the southern part of the Great Lakes region, but not in the northern. The Trent Valley outlet at Kirkfield, Ontario, had not then been visited by the writer, and Spencer's then recent rejection of it as a thing of importance was accepted. The name Lake Algonquin was applied to two different lake stages, the First Lake Algonquin and the Second Lake Algonquin. An eastward uplift separate from and later than the general northward uplift was postulated. On account of the incompleteness of the data then in hand and on account of the confusion introduced by erroneous postulates and interpretations, these two papers were both seen within a year to have been premature and except for a few passages are now worse than useless. Both include statements and interpretations bearing on the development of St. Clair and Detroit rivers and on Lake St. Clair and on the growth of the St. Clair delta which are almost all wrong.

The larger errors of these two papers were set right by investigation on the north shore of Lake Superior and in the Mattawa and Ottawa valleys in the fall of the year of publication (1895), and the corrected results were published in brief form the next spring.[6] After further studies in 1897 a more detailed though brief account of the features near Detroit was published.[7]

ST. CLAIR-DETROIT VALLEY.

The drainage system of the broad flat valley which lies between the south end of Lake Huron and the west end of Lake Erie must have had a long and complex history in preglacial times and in the times of the earlier ice sheets and interglacial intervals. It is not the purpose, however, to discuss this phase of its history here, but to present an account of the way in which the modern rivers became established after the recession of the last ice sheet. The outlet channels and connecting rivers which are now abandoned have already been described.

1 Niagara Falls and their history: Nat. Geog. Mon. No. 7, vol. 1, 1895, pp. 227, 229.

2 Recent earth movements in the Great Lakes region: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1897, pp. 601–647, especially pp. 605–606. Also more briefly in Nat. Geog. Mag., vol. 8, 1897, pp. 233–247.

3 Cole, L. J., The delta of the St. Clair River: Geol. Survey Michigan, vol. 9, pt. 1, 1903, pp. 1–25.

4 Sherzer, W. H., Geological report on Monroe County Mich.: Michigan Geol. Survey, vol. 7, pt. 1, 1900, p. 135.

5 The second Lake Algonquin: Am. Geologist, vol. 15, 1895, pp. 100–120, 162–179; Niagara and the Great Lakes: Am. Jour. Sci., 3d ser., vol. 49, 1895, pp. 249–270.

6 Preliminary notes on studies of the Great Lakes made in 1895: Am. Geologist, vol. 17, 1896, pp. 253–257.

7 Some features of the recent geology around Detroit (abstract): Proc. Am. Assoc. Adv. Sci., 1897, pp. 201–202.

The front of the ice sheet had retreated a considerable distance northward in the basin of Lake Huron before the waters of that basin fell to the level of the first or early stage of Lake Algonquin. In some of the stages just preceding this lake the outlet of the expanded waters was eastward along the northward-sloping escarpment near Syracuse, N. Y., and the pressure of the solid, impervious ice mass against that slope was still controlling the level of the waters in the basin of Lake Huron. At that time a strait, now occupied by St. Clair and Detroit rivers, connected the two lake basins. The flow of the waters through the strait could hardly have produced a perceptible current so long as the passage was wide and deep, but as the lake waters fell away the strait grew narrower and shallower and the current stronger, until it became a great river rather than a strait.

On the wide, flat floor of this connecting valley, transverse to the axis, run three low ridges, which, except where they have been cut through by the river, remain substantially as they were when the ice left them. Two of these ridges are morainic and one is partly moraine and partly bedrock. After the glacial lake waters fell St. Clair-Detroit River began to flow from the Lake Huron to the Lake Erie basin, naturally along the lowest line in the valley. It soon cut through the soft materials of which two of the ridges are composed and cut into the third to a depth of a few feet, below which it met more resistant materials.

In its first work the river produced two elaborate systems of distributary channels, one near the village of St. Clair on St. Clair River and the other near Trenton and Amherstburg on Detroit River. Most of the channels are shallow and must have been of very temporary duration, but they furnish an interesting record of the transition from a strait to a well-established river.

ST. CLAIR RIVER.

EARLY DISTRIBUTARIES.

EROSION OF THE MAIN MORAINE OF THE PORT HURON MORAINIC SYSTEM.

The highest of the transverse ridges and therefore the first to be uncovered and eroded by the newly established river is about 1½ miles north of St. Clair and is the southward water-laid extension of the main moraine of the Port Huron morainic system, here a single, simple ridge. Its crest is almost flat longitudinally, and is relatively broad and smooth. Figure 10 shows the distributaries on this moraine, the old river channel, and the esker on the plain south of it.

The moraine is 3 or 4 miles broad at its base, but it is low and its crest is broad and ill defined. From the end of its land-laid part northwest of Port Huron it runs south, forming the watershed between Pine River on the west and St. Clair River on the east. Near the north edge of St. Clair Township it turns southeast and after crossing the river extends east and northeast in Ontario. The highest points on the crest near the gap cut by the river have an altitude of about 645 feet above sea level or about 65 feet above St. Clair River. Northwest and north along the crest the altitude rises on the average not over 5 or 6 feet to the mile—in the first 4 or 5 miles only about 10 feet. Two or three gravelly knolls, probably outwash from the ice front, rise 10 to 15 feet higher than the general crest, but are not considered in the altitudes given.

On the Canadian side there were apparently no distributaries. A small creek flowing west of south from the moraine, about a mile east of Courtright, may possibly have been a small, very temporary distributary, but at the two points where it was visited by the writer it is very narrow and the evidence seemed clearly against this view. The first flow which had sufficient velocity of current to cut into the moraine was confined to a space about 4 miles wide extending southeast to northwest on the crest between Moore on the Canadian side and the southeast corner of sec. 1, St. Clair Township. Thus the overflow was in a general way toward the southwest over the western limb of the moraine. The gentle front slope here descends to the southwest and that direction was taken by the distributary streams. The group as a whole shows a slightly radial arrangement conforming to the curved front of the moraine—the western members running southwest and the eastern ones more nearly south. The present channels on the

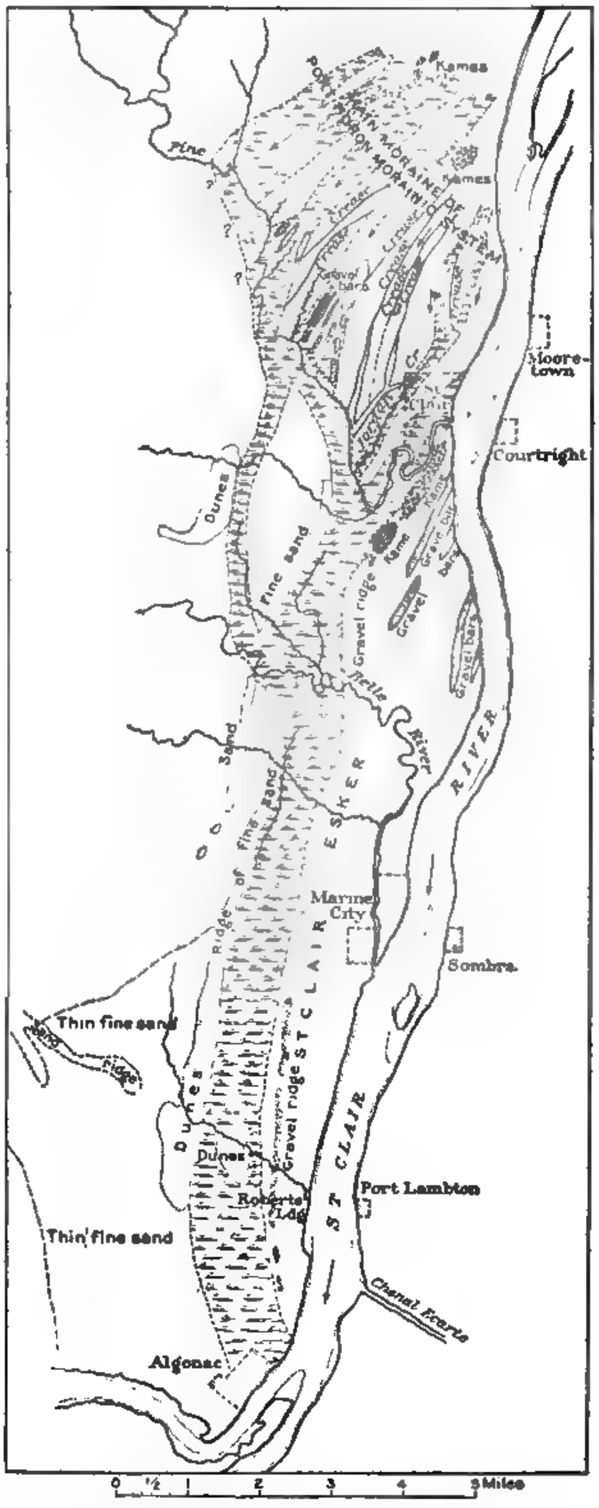


FIGURE 10.—Map of distributaries, gravelly river bars, the St. Clair esker, and other features near St. Clair, Mich. The river occupied both sides of the esker, but the space between the esker and the Canadian bank of the river is not now swampy and shows evidence of such occupation only in the gravelly bars south of St. Clair.

moraine range in width from nearly half a mile to only a few rods. The divided old river bed south of St. Clair, though resembling a pair of distributary channels, is not in reality of that nature. (See pp. 476–478.)

CHANNELS.

The distributary channels north of St. Clair were made at a higher stage of the lake waters than that which made the old river bed in the village, and the streams that made them were shorter lived. They lie in the eastern part of St. Clair Township and run southwesterly to Pine River. Measured by aneroid barometer their heads where they start on the crest of the moraine are 630 to 635 feet above sea level, the moraine crest being 5 to 10 feet higher.

The largest channel starts in southwest sec. 6 (east tier of sections),[1] St. Clair Township, and runs southwest through secs. 7 (east tier), 12, 13, 14, and 23, ending along the east side of sec. 22. It is nearly half a mile wide and is slightly swampy in some parts. It has a thin black soil, with scattered patches of sand and gravel. Toward its lower end it is floored with gravel across its whole width, and it bears two or three conspicuous gravel ridges which were deposited as bars where the current slackened in the Pine River valley. These gravels are best developed in southwest sec. 14 and northwest sec. 23. A prominent gravel bar is crossed by the diagonal road which runs southeast through sec. 23, less than a quarter of a mile east of the northwest corner. Some well-marked banks 5 to 10 feet high along the sides of this channel are in fact residual ridges forming barriers between it and other channels on either side. They are one-quarter to one-half mile wide, are composed of stony clay or till, and are simply parts of the original moraine which remained after the distributary streams had done their work.

Another channel starts in northeast sec. 7 (east tier) and runs southwest through secs. 13, 24, 23, and 26. It is like the channel just described, except that it is only half as wide and runs about a mile farther southwest. It is gravelly toward its lower end

[1] St. Clair Township is irregular, being made to include a tier of sections east of the regular boundary.

and contains gravel and sand bars in southwest sec. 24 and eastern sec. 26. At about mid length, in sec. 13, it grows somewhat indefinite. Little narrow, creaselike channels branch off on its west side, and it splits into a number of such channels toward its south end in secs. 23 and 26. In south sec. 1 two or three small channels start off to the west-southwest, but in south sec. 11 they fade out on a sandy plain.

Another better-developed channel lies east of those described and nearer St. Clair River. It has two headward branches that start close together, the western one in southeast sec. 18 (east tier) and the other in northeast sec. 19 (east tier). It starts at a lower level, its two heads opening at an altitude of about 620 feet (aneroid), and is more deeply eroded than the others. The eastern branch has a flat floor, swampy in places, and is 10 to 15 feet deep a mile south of its head. The floors are 20 to 40 rods wide above the point of union, which is in southwest sec. 30 (east tier). Throughout its whole length of 4 miles this channel is not over one-third mile from the bank of either the present St. Clair River or that of the old river bed in the village. It passes just west of the village and is the most striking old distributary channel of the locality.

It seems certain that the water flowed longer in this channel than in the others. Its altitude at its head is fully as high as the top of the higher ridge of the Lundy beach in this vicinity, so that it seems hardly probable that it marks the Lundy level, although it lies so near it. It seems rather to have been occupied until the lake level fell almost to the Lundy stage and then to have been left dry. It was on a slightly lower part of the moraine and was probably a little deeper at the start than the others. But although it was cut deeper the stream in it was relatively small.

CREASES.

Several shallow creaselike troughs start in west sec. 18 (east tier) and run southwest, curving south. Such creases are not known to occur except in association with the larger distributaries where St. Clair and Detroit rivers first broke over morainic barriers. They lie closely parallel to each other and 40 to 80 rods apart without branching or uniting. The intervening ridges are sightly convex in cross section and the creases are narrow at their bottom with no perceptible flat floor. Toward their heads some of them fade out on the nearly flat surface, but for most of their length they are 5 feet or more in depth. Three of them are more than 2 miles long. The S. ½ sec. 24 and all of sec. 25 are sprinkled with thin patches of gravel and sand, apparently deposited by water coming from the north over the creased ground. Two other creases, rather more pronounced, start in west sec. 13 and cross secs. 14 and 23 in the broader part of the till ridge between the largest two channels. Another crease crosses secs. 19 (east tier) and 30 (east tier).

It seems certain that the creases and the ridges between them are not original forms, but were produced by the first flow of the river over the moraine, for they are transverse to its crest. They appear to be the earliest recognizable product of erosion produced by the flow and to have been made when the water was flowing over as a thin, even sheet, mainly before any of the other channels had been eroded. Probably at first the whole slope now marked by the channels was creased in this manner. If the creases were made as supposed, by a thin water sheet, the level of which at their heads was gradually falling, then the quantity of water passing through them was diminishing while they were making and in a very short time ceased entirely. The whole process was too brief to permit the development of meanders, so the creases are straight or only slightly curved and have no flat bottoms. The direction of the creases records the direction of flow of the first water sheet as it passed over. On the lower parts of the moraine crest, where the water flowed longer, the creases were apparently cut away by the widening of the deeper channels. More and larger creases of this kind occur near Trenton. (See p. 489.)

The channels that have been described are all that remain to-day as abandoned distributaries, but at least one other distributary was deepened and became at last the channel of the master stream. This was presumably the largest one at first and as it enlarged and deepened its bed, the level of the waters north of the moraine was lowered and all the other distributaries were abandoned. Thus the largest of the original distributaries became the course of the undivided river. In its enlarged form it may include several originally independent channels.

GRAVELLY RIVER BARS SOUTH OF ST. CLAIR.

The concentration of the river in one channel north of St. Clair led to rapid downcutting through the soft materials of the moraine. At first the water evidently went through the gap with a rush and emerged on the flat plain south of St. Clair, where it spread in a relatively thin sheet 3 or 4 miles wide. Here it slackened and deposited long bars of gravel which it had washed out of the moraine and out of the newly excavated river bed to the north. All the gravel knolls and ridges south of St. Clair, however, are not of this description; a large ridge extending a mile southward from the Pine River bridge and another lying in central sec. 12, China Township, appear to be glacial.

The river bars lie east of the large glacial ridges, mainly in East China Township. They trend a little west of south, several of them being cut off at their heads by St. Clair River, which here runs south-southeast. One bar begins a little south of the Oakland Hotel and another nearly a mile farther south, near where the electric railroad turns west from the river bank. Two others run south from the bluff in sec. 18, East China Township. The bars have long, smooth, tapering forms and are a quarter of a mile to a mile in length, 2 to 6 feet high, and not over 300 feet wide. They are composed of sandy gravel and small pebbles, resting on clay, and are unmistakable river bars. A number of still smaller, shorter swells of sandy gravel of the same origin and trend are too small to be shown on the map. It seems probable that all of the bars were formed mainly during the active cutting of the river through the moraine rather than later when the channel had been completed and rapid cutting had ceased.

OLD RIVER BED SOUTH OF ST. CLAIR.

After quickly cutting through the Port Huron moraine the river reached a relatively stable state as the outlet of Early Lake Algonquin with a descent of about 10 feet from Lake Huron to Lake St. Clair. The Algonquin beach is 605 to 607 feet above sea level or, on the average, about 25 feet above Lake Huron, its level being determined mainly by obstructions in the lower part of Detroit River. (See p. 495.)

St. Clair lies mainly on a bench or terrace 10 to 12 feet above the river. The present river flows almost due south, but a steep bluff at the back of the terrace runs southwest for about a mile from the bank of the river at the north end of the village. The bluff is nearly 40 feet high in the village, but along the river to the north it rises steeply to over 55 feet above the water. Its highest point is about 1½ miles north of the village, just opposite the narrowest, deepest, and swiftest part of the river—the place where the river cuts through the main moraine of the Port Huron morainic system.

On emerging from its constricted passage through the moraine the river of the Early Algonquin stage entered abruptly on a wide, low plain. Evidently a strong current of the spreading river pushed southwest over the site of the village and cut into the moraine, making the conspicuous terrace and the high bluff behind it. The first of the large gravel ridges forms the prominent knoll just south of Pine River and west of the Oakland Hotel, and the flat between this and the bluff in the southwest part of the village is part of the abandoned river bed of that time. This runs southwest through secs. 1, 11, and 12, China Township, turns directly south to the middle of sec. 24, bends a little to the west, and continues in a straight line to west of Roberts Landing, south of which it gradually fades away on the low sand-covered clay plain. In St. Clair it is from one-third to one-half mile wide, but farther south it is three-fourths of a mile to a little more than a mile in width.

On entering the old river bed Pine River turns abruptly from southeast to northeast. A short distance south of the bend the floor is about 15 feet above St. Clair River, and it declines very gradually southward to 3 or 4 feet above the river west of Algonac. The floor was originally nearly all a swamp and a considerable part is so still. The banks are rather peculiar; below Pine River they show very little evidence of scour by the old river. The west bank appears to be a cut bluff in some places, but the cut is now obscured by fine sand which forms a narrow,

more or less duny ridge for nearly the whole length. In some places the sand knolls are pronounced, especially toward the south end, where the sand belt broadens. A few dunes have apparently traveled from west of the road northwest of Roberts Landing over into the middle of the swamp. Southward from sec. 10, Cottrellville Township, the sand belt widens to a mile or more.

ST. CLAIR ESKER.

The east bank of the channel is not continuous but is nearly so and is composed in most places of a narrow ridge of gravel. For 2 miles south of St. Clair the large glacial ridge mentioned forms the bank, the gravel in the ridge being fairly coarse. Southward the ridge is lower, almost disappearing in some places. In places where it is low it appears to be partly composed of clay and is generally 30 to 40 rods wide. The cemetery 1½ miles west of Marine City is on this ridge.

The ridge in all is 11 or 12 miles long and its relations and origin are somewhat obscure. It is thought to be a product of glacial drainage and is apparently an esker made in an ice tunnel or canyon when the ice front was somewhere south of Roberts Landing. In one or two places (for instance, in the bank of Pine River south of St. Clair and where the ridge is cut out by Belle River west of East China) the gravel appears to rest on clay. The ridge is not prominent west of Marine City, but grows stronger a mile or two farther south and is a strong beachlike gravel ridge for about 3 miles to a point southwest of Roberts Landing.

The difficulties in finding a clear and satisfactory explanation for the origin of this ridge are greatly increased by its relations to three other forms of gravel deposit. In its northern part just south of St. Clair it falls in line with the heavier knolls which are regarded as kames and which may possibly be related to an early position of the ice front at the time of the Port Huron morainic system or possibly to a less pronounced halt of an earlier date. In its northern part it is also closely associated with some of the gravelly river bars. It is here fainter and more broken and is rather more sandy and clayey than it is farther south. It may have been modified to some extent by the rushing of the early river over it.

In its stronger southern part its crest happens to lie through much of its length almost exactly at the level of the first St. Clair beach (correlative of the Algonquin beach), faint markings of which, found at and below Courtright, on the Canadian side, show the altitude at which the waves acted. This relation seems to be accidental, for all the shore markings at Courtright and at other points in this part of the basin of Lake St. Clair are extremely faint, consisting merely of a faintly cut notch or a sandy or gravelly belt with scarcely noticeable ridging. The ridge west of Roberts Landing, on the other hand, is composed of fairly coarse gravel and stands 12 to 15 feet above the clay flats on either side. The ridge as seen from either east or west has the appearance of a beach ridge or spit as strong as the Whittlesey and Warren ridges. Its situation, however, is such that it is impossible for it to have been built primarily by wave action. Lake St. Clair is so small a body of water and it was so shallow, even in the time of Early Lake Algonquin, that wave action in it must always have been relatively weak. The gravel ridge widens somewhat toward its southern end in a way that is characteristic of the termination of eskers. Besides, the trend of this ridge is southward along the axis of the St. Clair Valley and not at all what would be expected as a product of wave action from Lake St. Clair, where the most effective waves would come from the south. Hence, though the crest of the ridge appears to have the form of a wave-built deposit and, indeed, has probably been fashioned somewhat by waves, the ridge itself is to be regarded as an esker rather than a beach.

From 2 or 3 miles north of Marine City southward into the St. Clair delta all the low ground on both sides of the gravel ridge is composed to a depth of several feet of lake clay without stones.

In another respect the conditions surrounding this ridge were unfavorable to production by waves. Not only was there no wide deep water to provide waves sufficiently heavy to form such a deposit, but the ridge stands out alone on the flat clay floor of the valley with no visible source of supply for its material. No sea cliffs of stony till and nothing corresponding to a

surf-wasted zone lie near, unless buried under the lake clays. Even if such a zone be present, it is more than 20 feet below the ridge crest and can not be accredited to the waves of so small a lake. On the other hand, these characteristics of situation, trend, composition, and height of the ridge with parallel depressions or flats on the two sides are characteristic of eskers. The feeble waves of Lake St. Clair in the time of Lake Algonquin may have in some degree fashioned the gravel along its crest, but they could have done nothing more.

This gravel ridge, as already stated, lies along the central axis of the St. Clair Valley. At the time of Early Lake Algonquin it divided the bed of the river southward from St. Clair into two channels of probably nearly equal capacity. They appear to be troughs associated with the esker. The river at this stage endured through the time of Early Lake Algonquin and the early part of the third or Port Huron-Chicago stage—long enough for Lake St. Clair to build a distinct though not strong shore line and for the river to accomplish a well-defined work of erosion and deposition. It seems certain that during this early stage of the river the part of its bed which lay east of the esker became deeper than that which lay west, so that later, when Lake St. Clair fell to a lower level, the river abandoned the western channel and became concentrated in the eastern one, in which it now flows.

ST. CLAIR DELTA.

SOURCE AND CHARACTER OF MATERIAL.

The delta of St. Clair River in Lake St. Clair is exceptional from the fact that it was built by the outlet river of one of the Great Lakes and by water generally supposed to be clear and free from sediment. (See fig. 11.)

The peculiar relation of St. Clair River to Lake Huron has been the chief cause for the formation of the delta. Storm waves on the south shores of Lake Huron have done and are still doing a tremendous work cutting away the bordering lands, in some places cutting back 5 to 6 feet a year, as established by measurements and surveys.[1]

+ The storms that do the most effective work on these shores come from northerly directions and tend strongly both by oblique wave action and by wind-driven currents to carry the sediments derived from the cutting toward the south end of the lake. The same thing occurs in Lake Michigan where there is no natural outlet and where the sands have consequently accumulated in enormous quantities as dunes about its south end. Storms make the water of Lake Huron roily all along the shore and for some distance out into the lake. St. Clair River opens from the southern extremity of the lake and the roily water is carried into the river and down to Lake St. Clair. Here, on meeting the still water, the finer sediments are deposited, and it is mainly through a long continuance of this action that the delta has been built. A considerable amount of sand and some gravel also are rolled along the bottom and are added to the delta deposit.

An excellent detailed study and discussion of the St. Clair delta was made by Cole[2] for the Michigan Geological Survey. His investigations show the delta to be in nearly all respects a normally formed, low-grade (fine sediment) delta, though having some peculiarities and some exceptional features. Cole made 31 borings in the delta and found clay of varying quality to be the main constituent, with considerable quantities of sand and sandy clay. At a certain depth, generally 12 to 17 feet, the borings penetrated a stiff blue clay which in a few feet became soft and waxy and continued uniform in texture to an indefinite depth, in one boring to at least 56 feet. Borings at Algonac and Port Huron show this "bottom clay," as Cole calls it, to be 80 to 100 feet deep at Port Huron and 150 to 200 feet deep at Algonac. In several borings, at a depth of 11 to 12 feet below the level of Lake St. Clair, Cole found beds of muck composed of decayed vegetation resting on the stiff top layer of the "bottom clay."

[1] Gordon, C. H., Wave cutting on west shore of Lake Huron: Ann. Rept. Michigan Geol. Survey, 1901, pp. 283-290, Pls. XI-XV.
[2] Cole, L. J., The delta of the St. Clair River: Michigan Geol. Survey, vol. 9, pt. 1, 1903, pp. 1-25.

As Cole points out, the "bottom clay" fills all the lower parts of the valley between Lake Huron and Detroit, and is in fact a great deposit of lake clay laid down probably in the large glacial Lakes Arkona, Whittlesey, and Warren. The ice barrier is known to have stood a mile north of St. Clair for Lake Whittlesey, and somewhere in the south part of Lake Huron for Lakes Arkona and Warren.

The sediments contributed to the delta are derived from three sources: Streams tributary to St. Clair River bring in moderate quantities of sediment in times of flood; the river itself erodes its banks and bottom, cutting away the banks rapidly in a few localities and carrying the material to the delta; Lake Huron contributes sediments cut away during storms. Cole

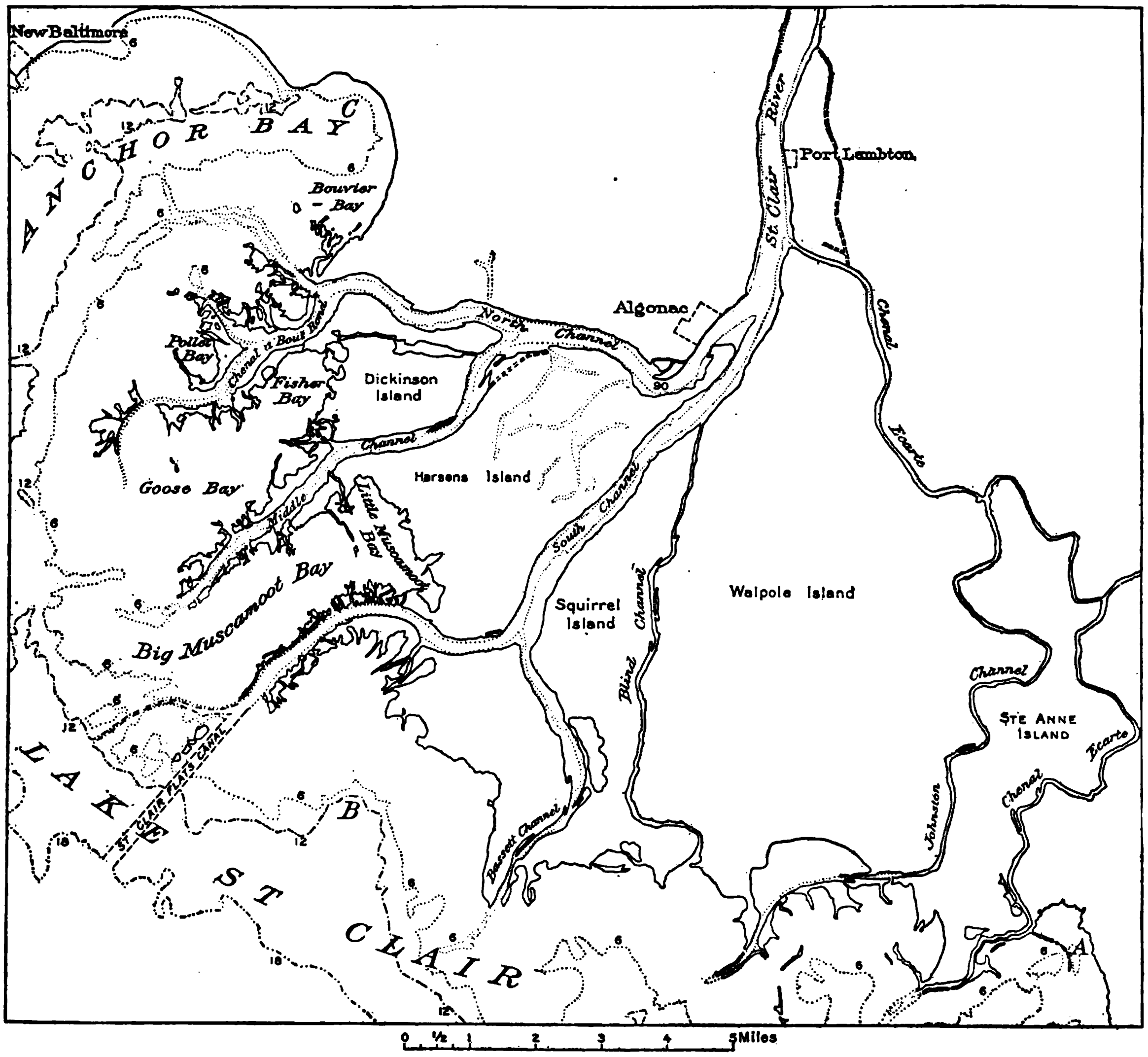


FIGURE 11.—Map of St. Clair delta.

quotes interesting estimates made by O. B. Wheeler [1] of the United States Lake Survey, on the amount of sediments derived from this last source. The estimates have considerable elements of uncertainty but seem to show that the quantity is at least twice as great as that derived from all other sources.

CHARACTER OF THE DELTA.

Some of the more important facts stated by Cole and by Lane in an introduction to Cole's report may be summarized as follows: From its head to its front the delta measures nearly 15 miles on a line running south-southwest from the head of Russell Island. Transverse to this

[1] Rept. Chief of Engineers U. S. Army, 1885, pt. 3, pp. 2199-2202.

line its width is about 20 miles and it is estimated to have filled about one-quarter of Lake St. Clair. The delta is made up of islands separated by somewhat winding distributary channels. It has not all been made with the lake at its present level, for the ground toward its head stands about 6 feet above the mean level of the river. The surface of the delta is extremely flat and slopes very evenly, its front being a submerged flat 2 to 3 miles wide. Its outer edge is fairly well defined at a depth of 6 or 8 feet by a rather definite bank from which the descent is relatively abrupt to the deeper part of the lake. The greatest depth of the lake is 22 feet, with a general depth in the central part of about 20 feet. Thus, the delta surface slopes 12 feet from head to front but slopes a little more rapidly near the submerged edge.

The steepness of the sides of the channels under water is most remarkable, being sometimes almost vertical for a distance, while a greater dip than 45° is probably characteristic. There are nine channels, including Baltimore channel and the ship canal, which have a depth of over 3 fathoms to the bars at their mouths. Throughout the most of their length the main channels have an average depth of about 30 to 40 feet, but the north channel, in the large bend south of Algonac, reaches a depth of 90 feet and is 60 feet and more deep to some distance below the North Channel clubhouse at the junction of the Chenal a Bout Rond. The river above the head of the south channel ranges in depth from 30 to 60 feet.[1]

Toward the head of the delta large areas on Russell, Herson, Squirrel, and Walpole islands are well above mean water level, are partly covered with heavy forests, and partly under cultivation. The height of these islands above mean water level shows that they were built when Lake St. Clair stood higher than now. The fall in the lake level has caused the river to deepen its channels through the older parts of the delta.

A glance at the excellent chart of Lake St. Clair by the United States Lake Survey (edition of August, 1908, or later), which is indispensable for studying the outline of the delta and the width and depth of its various channels, shows that the delta as a whole is divisible into two main parts, the old and the new. The dividing line is along the east side of the South Channel. Squirrel, Walpole, and Ste. Anne islands and probably the marshy flats west of the Bassett Channel belong to the old part. Russell, Herson, and Dickenson islands, though their higher or northern parts are probably as old as Walpole Island, are associated with the new channels and the newly made part of the delta. There are, however, some evidences that Herson Island is partly of relatively recent date, for irregular shallow sloughs run through its northern half in several directions. The islands east of the South Channel show no such features containing water.

The moving current of the river carries the fine sediments in suspension when the water is roily and rolls the sand along the bottoms of the larger channels. The growth of the delta takes place chiefly in the shallow waters along the sides and around the ends of the channels, where these are active and reach nearly to the delta front. Big and Little Muscamoot, Goose, and Fisher bays are being gradually filled up in this way. Even where the channels are deep to within a mile of the submerged edge of the delta, they end abruptly in the shallows behind a wide flat bar. As the platform of the delta is built out the deep channels follow, but never open directly into the deeper part of the lake.

CHANNELS OF THE NEW DELTA.

The channels now active are the South, which is the principal line of navigation, and the North, which has two branches from its south side, the first of which is called the Middle Channel and the other, farther west, the Chenal a Bout Rond, or locally the Sny. The main line of the North Channel, which runs westward from Algonac, is the largest in cross section, has the swiftest current, and carries the largest volume of water. The upper part of these channels, for 3 to 4 miles below Algonac, are simply deepened passages through the older part of the delta and vary from an eighth of a mile to half a mile in width. The land there is slightly above high water and can hardly be said to be growing. Farther out, however, the channels pass beyond the dry-land surface and run for 4 or 5 miles out into the shallows of

[1] Cole, L. J., Michigan Geol. Survey, vol. 9, pt. 1, 1903, pp. 6-7.

the submerged growing parts of the delta between narrow but very ragged and irregular belts of land barely above the mean level of the lake. These form natural levees, broken by many small crevasses through which the water pours into the very shallow bays along the sides. The moment the roily water leaves the deep channel it slackens and deposits the coarser parts of its sediments. Thus the ragged low levees have been built up by the distributaries themselves, and each little crevasse in these levees tends to build its own smaller levees out into the shallow bay into which it enters. These levees in turn are worn away and destroyed by the feeble action of the waves which run in over the shallow bays.

FRONT OF THE NEW DELTA.

That growth is at present active in the western part of the delta is shown by the long ragged fingers of the South and Middle channels and the Chenal a Bout Rond, each of which projects its levees about 4 miles beyond the general land front of the delta. The whole area between the active channels and for a mile or more beyond their ends has been extensively built up in recent times and is still actively growing.

The limits of the newly built delta are clearly shown by the soundings. The new part, which is about 10 miles long from north to south, has been added to the west side of the older delta and projects into the bed of the lake about 5 miles westward from the ill-defined land margin. The 2-fathom (12-foot) contour shows a well-marked reentrant about halfway between the ship canal and the south end of the Bassett Channel. It runs about 1½ miles northward into the front of the delta and marks the southeast limit of the newly made part. On the north side the same contour shows a narrow unfilled part of the lake running east to the mouth of Swan Creek from the deeper part of Anchor Bay. The wider, deeper part of Anchor Bay defines the western front.

CHANNELS OF THE OLD DELTA.

In the size and character of its channels and in its relatively smooth south front, the old part of the delta east of the South Channel presents a strong contrast to the new part just described. The principal channels in the old part are the Chenal Ecarte and the Johnston Channel, which branches from it, the Blind Channel, and the Bassett Channel.

These channels, especially the Ecarte and Johnston channels, are very crooked and narrow, being generally not over 400 feet wide. The water is generally 20 to 30 feet deep, but is reduced on bars to 15 to 17 feet. The Blind Channel, which branches from the South Channel a mile below the head of Russell Island, is more nearly dead than any other that still carries water. At its head it is only 2 feet deep and is very narrow, and through most of its length it is not over 10 to 15 feet deep. An extinct channel, which leaves the river 2 miles above Port Lambton and runs south to the Ecarte a mile below its head, is the oldest known channel of any length.

The Chenal Ecarte leaves the river 2 miles above Russell Island, and it and the Johnston Channel seem more like artificial canals than natural distributaries. Still, they are of a type common in deltas. They are not intensely active like the North Channel, but seem to have reached a stationary or balanced state, and although half dead and substantially unchanged for a long time, they do not become closed. The Blind Channel has progressed further toward extinction and will probably be closed at a not distant date.

The Bassett Channel, which branches from the South Channel at the great westward bend, is a dying distributary. Its deep part is not wider than the Ecarte, but for 2 miles down from its head it is bordered on one side or the other by shallows 400 to 800 feet wide. This channel has not progressed so far toward extinction as the Ecarte, which was once large like the South Channel of to-day but has become gradually contracted and now has scarcely any shallows along its sides. Water plants, such as sedges and rushes, are important agents in the contraction of these channels, when once they begin to decline. The plants slacken the roily waters

and thus induce deposition of sediment and build up the banks. The Bassett Channel was evidently once of large dimensions and is still in process of contraction.

FRONT OF THE OLD DELTA.

Another evidence of greater age in the eastern part of the delta is its lack of long ragged levees along the outer parts of its old channels. Some ragged points are associated with the Johnston and Ecarte channels, but they appear to be battered fading forms. None accompany the Blind Channel, and only two or three fading remnants border the Bassett Channel. The whole land front of the old delta has been much smoothed as compared with that of the new.

RECENT AND PROGRESSING CHANGES IN THE CHANNELS.

The aging or extinction of the older channels suggests the future of some of the newer ones. The present active channels are not all in the same condition. One is aggressively active, actually enlarging, and others are evidently dwindling.

Throughout its whole length the North Channel seems to have the strongest flow. It is on the average slightly deeper and wider than the South Channel and is the master stream and would be the best route for navigation if it extended in a southwesterly direction. It seems certain that until recently its waters followed the Chenal a Bout Rond, which is lined with ragged levees as large as those of either the Middle or South channels, but which has so dwindled in recent times that its deeper bed is now narrow and is bordered by wide shallows. It is not very long since the bank between Point aux Trembles (where the main line of the North Channel turns northwest) and the North Channel clubhouse was continuous across the present North Channel or was broken by only a small crevasse. But some circumstance, perhaps an ice jam like that which Cole describes as affecting the river higher up, forced a powerful current through it to the northwest and established a new route. This part is so new that it has not yet built any levees along its sides, those on the two sides near the clubhouse being parts of the older levee.

The Middle Channel, which branches from the North Channel 2½ miles west of Algonac, is also dwindling but has not shrunk so much as the Chenal a Bout Rond. The South Channel has also dwindled and is now distinctly second in importance to the North Channel. Under present conditions the North Channel has a decided advantage over the other channels and is evidently gaining on them, for from the head of Russell Island to the open water of Lake St. Clair a quarter of a mile northwest of Point aux Trembles, the distance is 3 miles shorter than to the open water at the Old clubhouse on the South Channel. It is characteristic for delta distributaries to change and shift about, and just now the North Channel seems to be robbing the others.

If the South Channel is to continue to be the main route of navigation steps ought to be taken to prevent its further dwindling if not to enlarge and improve it. This could be done by diversion works above Algonac so arranged as to guide into it a larger proportion of the river.

No doubt there was a small natural crevasse near Point aux Trembles before the main current broke through, and this probably determined in part the course of the scouring current at that time. Artificial cuts through the natural levee, such as have been made at many places in the flats above the ship canal, are a menace to the maintenance of the deep channel. By drawing off the water they slacken the flow in the channel and tend to increase deposition of sediment.

AGE OF THE DELTA.

The muck beds described by Cole appear to rest on the surface of the lake clay which underlies the whole region. The muck evidently dates from one of the times when the upper lakes were discharging eastward by other outlets and St. Clair River ran dry. Under the muck, Cole generally found 2 or 3 feet of tougher clay marking the upper part of the lake clays. This tough stratum appears to be an old land surface and was generally present, even where the muck was absent.

Twenty-nine of Cole's thirty-one borings are on the new delta, and one is on or about on the dividing line between the new and old. Only one is distinctly on the old. Six borings penetrate muck beds, and five of these are on the new delta. One is on the North Channel at Point aux Trembles, three on the Chenal a Bout Rond (two at one place), and one on the Middle Channel. The sixth is on the west side of the Bassett Channel, about half a mile south of its head, or about on the dividing line. The one boring on the old delta is east of the dividing line a little below the head of the Blind Channel. It disclosed deep muck at the surface but no buried muck or hardened lake clay.

It is inferred that all the buried muck beds found, with the possible exception of the one on the Bassett Channel, date from the discharge of the upper lakes through the North Bay outlet. The muck of the boring on the Bassett Channel may be of the same origin. At any rate, it can hardly be taken as sufficient proof that buried muck and an old land surface exist under the old part of the delta, and that the delta holds similar records of the discharge of the upper lakes through the Trent Valley outlet. The boring on the Bassett Channel is offset by that on the Blind Channel, in which no buried muck or hardened clay was found. The substratum of the old delta remains to be investigated.

The flow of St. Clair River before the opening of the Trent Valley outlet was probably too brief for important delta growth. In that event the only important period of delta growth before the present one was during the time of the third or Port Huron-Chicago stage of Lake Algonquin. The level of St. Clair River was at that time higher than now and the delta was built to a higher level. The old dry distributary which runs south from 2 miles north of Port Lambton suggests a delta head perhaps as far north as Marine City and at a higher level. The delta head near Algonac, with surface 6 feet above the present river, seems related more nearly to the time of the Nipissing beach (transition phase), which was the beginning of the modern lakes. It stands close to that level.

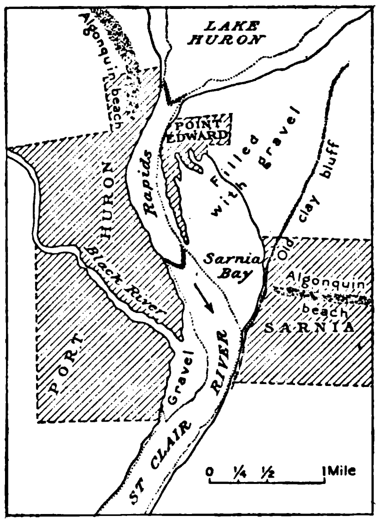


FIGURE 12.—Map of Point Edward spit.

Since the closing of the North Bay outlet St. Clair River has flowed continuously as the outlet of the upper lakes. If the old and new parts of the delta correspond to definite parts of the lake history the new part was probably made since the closing of the North Bay outlet and the old part during the southward discharge (Port Huron-Chicago stage) of Lake Algonquin.

In discussing the history of delta growth, Cole makes use of one factor which has since been eliminated. He estimates the effect of the northward tilting of the land which is supposed to have continued through recent times to the present and to be still progressing and discusses its effect on the supposition that the delta and Lake St. Clair lie within the area of the progressing uplift. The idea is an application of conclusions reached by Gilbert,[1] in a study of recent and present land movements in this region. It has since been found, however (pp. 439, 449), that the hinge line of the uplifted area passes across the "thumb" and the south part of Lake Huron, so that St. Clair River and Lake St. Clair with the delta are not affected by recent deformation or tilting.

GRAVEL SPIT AT HEAD OF ST. CLAIR RIVER.

A gravelly deposit, here called Point Edward spit, lying at the head of St. Clair River, on the Canadian side (see fig. 12), is a distinct correlative of the newer part of the St. Clair delta (p. 484). It has played an important part in the history of the river and has produced a marked effect on the American shore. Studies of this locality still lack much of completeness, but the general relations of the deposits have been determined.

[1] Gilbert, G. K., Recent earth movements in the Great Lakes region: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898, pp. 595-647.

Gravel and sand are constantly drifting southwest along the Canadian shore into the head of St. Clair River, where they have been deposited as a southward-pointing spit 1½ miles long. As the gravels were rolled into the opening the strong current swept away the finer particles and dropped only the coarse material, adding layer after layer of coarse gravel to the westward front of the spit, and constantly crowding the river over against its western bank. The current in the rapids flows 4½ miles an hour, and the relations show plainly that the existence of the latter is due to the narrowing of the river caused by the growth of this gravel mass westward.

On the American side there is no spit, but a much smaller bar or shoal appears farther down the river. The west bank of the rapids has no protection against the swift current and is eroded away as fast as the gravels on the east side press westward. Continual adjustment is in progress and has been for a relatively long time, the river at Fort Gratiot having gnawed westward into the clay land about a mile from its original position.

The alignment of the Canadian shore of Lake Huron with reference to the head of the river favors the formation of a spit, and that on the American side does not do so. Gravel carried into the head of the river from the north on the American side is swept along the bottom of the river, and probably added to the shoal off the mouth of Black River. It seems doubtful whether much coarse gravel could be swept through the whole length of the river to the St. Clair delta.

It seems probable, however, that the relative quantity of gravel brought in from the two shores is much more important than their alignment. The Canadian shore faces west and northwest and receives the full force of the heaviest storms. The Michigan shore faces east and is not so severely attacked. Both shores have been heavily eroded in the past and are still receding, but the length of shore tributary to the head of the river is considerably greater on the Canadian side. Cole does not accept this explanation of the rapids in his report, but he looks at the matter from a slightly different point of view.

The gravel mass at Point Edward measures 1½ miles from east to west and about 2 miles from north to south. The deposit appears to be all of modern or post-Nipissing age. At the time of Lake Algonquin the entrance to St. Clair River was a wide tapering bay opening northward from Corunna; and the gravels of the Algonquin stage, except for one prominent bar upon which the London road enters Sarnia, lie north and northeast of Sarnia and are quite separate from those that have displaced the river at Point Edward. The deposits related to Lake Algonquin have not been fully investigated.

The Point Edward spit is the correlative of the new part of the St. Clair delta. Every north or northwest storm cuts into the great clay cliffs on the Canadian shore, roils the water in the shallows, and stirs up the gravel. The shore current bears the roily waters along and rolls the gravel toward Point Edward. Once there they separate, the coarse materials and gravel being added to the great spit and the fine sediments being carried down to Lake St. Clair and built into the delta. The main part of the spit has been built since the closing of the North Bay outlet. The process has a peculiar international relation; the shores of Lake Huron on the Canadian side are being torn away, and though the coarse material is mainly left at Point Edward on the Canadian side, nearly all the fine sediment is carried down the river and built into the new St. Clair delta on the American side.

LAKE ST. CLAIR.

The body of land which projects into the west side of Lake St. Clair on the two sides of Clinton River looks like a delta on the map but is shown by Cole's investigations to be mainly glacial till carrying bowlders—probably part of the Emmett moraine. Only about 800 acres of it along the outer front is of the nature of a delta, and Black Creek, which flows southward through it, is the only distributary besides Clinton River that crosses it.

Salt Creek, west of New Baltimore, and Swan Creek, west of Fair Haven, have produced only very small salients in the shore line.

DETROIT RIVER.

DETROIT RIVER AT DETROIT.

DISTRIBUTARIES.

The next ridge which obstructed the flow of the new river was the low interlobate moraine which crosses the river at Detroit and upon which the higher parts of that city and of Windsor, Ontario, are built. This ridge is so broad and flat that it is scarcely perceptible to the eye as such, except where seen in cross section along the bank of Detroit River. The bank is noticeably higher along the city front, standing 30 to 35 feet above the river, than it is either

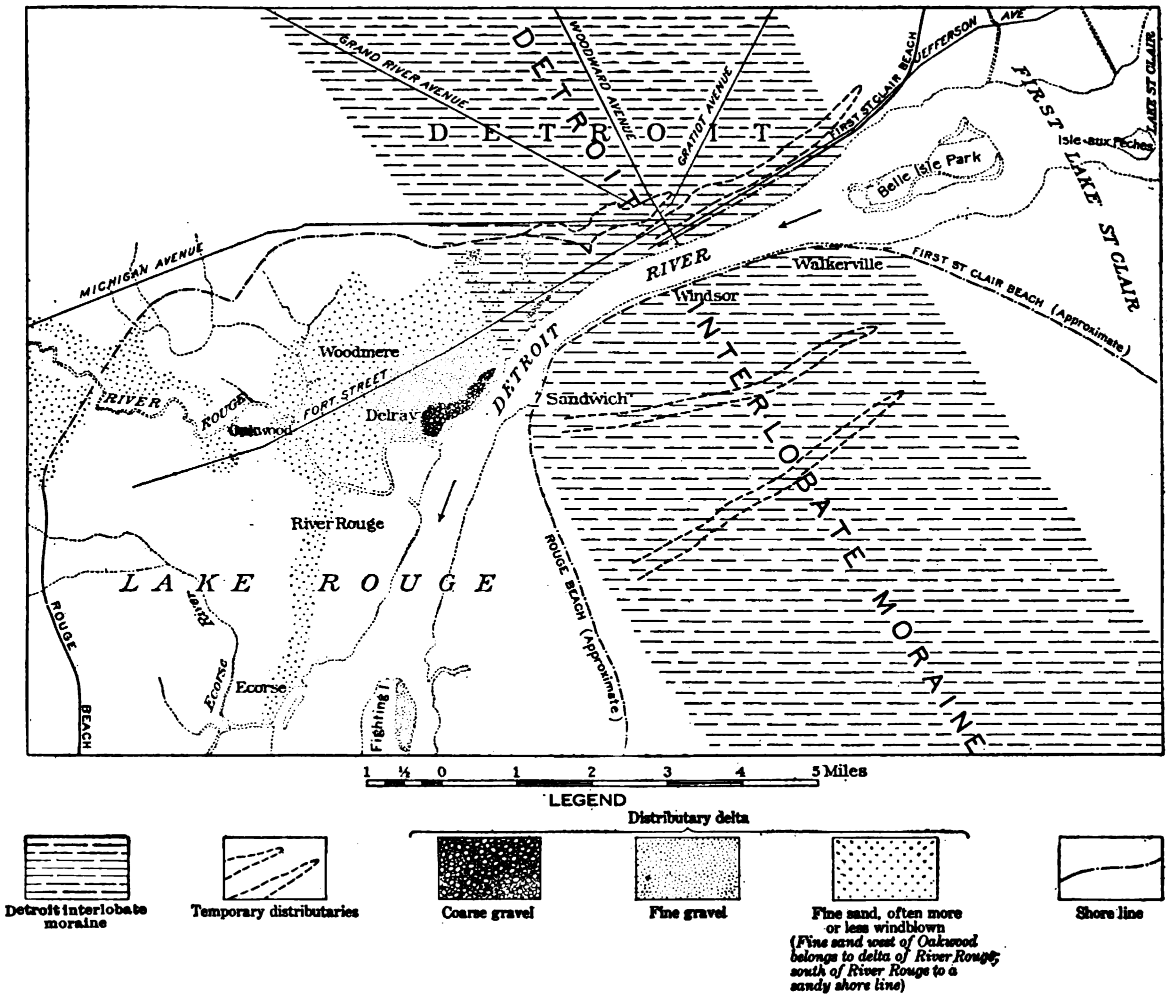


FIGURE 13.—Map showing distributaries of Detroit River at Detroit and delta in Lake Rouge.

east or west of the city, where it falls away to a reedy marsh at the level of the river. From the river bank half a mile east of Woodward Avenue the axis of the ill-defined ridge runs about northwest. In Canada it runs about southeast from Windsor nearly to the shore of Lake Erie, before turning northeast. This moraine has already been fully described (p. 284).

There appear to have been two distributaries on the Canadian side, one called the Grand Marais, about a mile back, and another farther out. Both are very shallow and not well developed. Those in Detroit are small and close to the river, the farthest being less than a mile from it. (See fig. 13.) Probably a well-marked depression or sag already existent in the crest of the moraine was followed by the river, for otherwise distributary channels would cover a wider interval on the moraine crest, as they do at both St. Clair and Trenton.

Between the city hall and Jefferson Avenue, which lies on a distinct ridge, Woodward Avenue crosses a well-defined depression running nearly parallel with the river. The Jefferson Avenue ridge extends from about Cass Street eastward along Jefferson Avenue to the vicinity of St. Aubin Avenue. The depression north of the ridge is very distinct for a considerable distance, but it gradually fades away toward Elmwood Cemetery, though it possibly continues in faint form to Champlain Avenue, to the boulevard north of the Belle Isle bridge, and thence about half a mile farther to the vicinity of Kercheval and Burns streets. In this part of the city the contour of 600 feet above sea level bends from the north around to the south and then to the west, showing a long, low point projecting from the vicinity of Burns and St. Paul streets about to Baldwin Street and Champlain Avenue. The depression behind this point lies in such a position as to form a natural continuation of the trough farther west, and may represent a part of the same distributary channel, although this is not certain. The grading and filling connected with the improvement and growth of the city have so altered the original surface that a slight depression might have been obliterated. Congress Street lies about in the trough of this old distributary, at least as far east as St. Aubin Avenue. In its western part this depression was originally much deeper than it is now, and was, in fact, the site of a small drowned creek which in the early days formed the harbor of Detroit for the small craft of that time. The deepening of the creek and its subsequent drowning are both later than the time of the distributaries. (See pp. 499–500.)

Another irregular depression begins three or four blocks east of Grand Circus Park and extends with some irregularities westward across Woodward Avenue and Washington Park and along Labrosse and Baker streets as far as Tenth Avenue where it fades away on a thin deposit of sand. This was not originally so deep as the other, and is less regular, apparently indicating that it was occupied for a shorter time.

Both of these channels are relatively short and irregular and, in comparison with the more typical examples at St. Clair and Trenton, their identification as distributaries might be regarded as doubtful. But for their position, transverse to the axis of the moraine and parallel to the river, and their relation to sandy deposits made by the river in cutting through the ridge they might be interpreted as merely accidents of morainic deposition. It may be noted that both of them head on the higher part of the ridge and that their bottoms descend toward the west as though they were eroded by currents flowing in that direction. Neither is a quarter of a mile wide, at some points half as much, and probably neither was originally more than 10 to 15 feet deep.

LAKE ROUGE.

The imperfect distributary channels just described were evidently abandoned early in the cutting of the ridge, for, beginning two squares northeast of the fort at Fort Wayne in the southwestern part of the city and extending west for about half a mile, there is a very well marked gravel and sand deposit, apparently a river bar formed at the head of a delta. The fort and the officers' quarters are on this bar. It appears to have originally extended perhaps a quarter of a mile farther northeast but to have been cut away by the modern river. At the fort and in the lots northeast of it these gravels are rather coarse and clean and the deposit is heaped up 6 or 8 feet higher than the surrounding ground. Toward the southwest this deposit spreads rapidly in passing into Delray and at the same time becomes lower and thinner and of finer texture. The gradation within half a mile from coarse gravel to sand fine enough to be blown by the wind is very striking.

Between the fort and West Detroit and in the vicinity of Clark Park there are a number of irregular deposits, some of them of gravel, like that at Twenty-fourth and River streets, at Twenty-first and Standish streets, and at Scotten and Toledo streets; and others of sand, like that west of St. Luke's Hospital and on the boulevard north of Lafayette Street. Thinner deposits of sand cover most of the surface at Woodmere and Delray, and there are a few duny ridges of fine sand, like that which begins a quarter of a mile south of West Detroit and follows the line of Dix Avenue. There is also much thin sand in the vicinity of Woodmere Cemetery,

on the west side of Baby Creek and in the western part of Delray. Other duny sand ridges along Rouge River in Springwells Township may have had a different origin, but all the gravels and sands in the southwest part of the city and in Woodmere and Delray were evidently deposited when the river first broke through the moraine. (See fig. 13.)

The cutting through the moraine at that time was evidently not very deep, and the low ground along Rouge River southwest of the city was occupied by a shallow lake or expansion of the river which may be called Lake Rouge. In this lake the gravel and sand derived from the cutting of the distributaries and the main channel were deposited as a scattered thin delta. That this is really the explanation of these gravel and sand deposits seems clear from their relation to the river. The main channel at that time must have been the same as at present, but was not so deep. It was probably not excavated much below the present surface of the river, and southwestward toward the fort, where the river entered Lake Rouge, it was probably not excavating at all, but spreading out widely and depositing gravel and sand. The gravels at the fort stand precisely in line with the cut of the main channel through the moraine and exactly where the spreading, slackening current would drop its load on emerging from the narrow cut. A considerable part of this gravel deposit, the eastern part of the bar especially, has probably been cut away by the modern river. One or two gravel bars were made at the same time on the Canadian side, the largest being on the north part of Fighting Island. The relations of all these features taken together present a very clear record of the river's first cutting through the moraine.

Lake Rouge covered the south half of Springwells Township and nearly all of Ecorse Township, reaching down to the head of Grosse Isle. It was 10 or 12 miles long from north to south and at least 6 or 7 miles wide, but its precise limits on the Canadian side have not yet been determined. So small a body of water could hardly be expected to develop perceptible shore lines, but Lake Rouge did develop a faint but well-defined one on its west side and on the north end of Grosse Isle. From the rear light of the Grosse Isle north channel range lights a faint ridge of gravel runs south for a couple of miles just west of the beach road. Most of the cottages are built upon it. Its altitude at the north end of Grosse Isle is about 13 feet above the water, or about 588 feet above sea level. This is about 7 feet below the first St. Clair beach in the basin of Lake St. Clair. This beach of Lake Rouge, or the first Rouge beach, as it may be called, is also a correlative of the upper Algonquin beach and marks another step in the descent from Early Lake Algonquin to the Lake Erie basin.

DETROIT RIVER NEAR TRENTON AND AMHERSTBURG.

The finest development of abandoned distributaries is in the vicinity of Trenton and Amherstburg. The new river here found obstructing its flow a broad, flat-topped ridge which was composed in part of ordinary till like the ridges already described, in part of a bowlder bed set in very tough till, but in part of limestone in massive beds. As at St. Clair, the crest of the ridge appears to have extended northwest and southeast, so that, when the river first flowed over it, most of the distributaries tended to flow southwest. Plate XXXI shows the distributaries in the vicinity of Trenton and Amherstburg.

The distributaries of this locality are extremely complex. There are early ones and later ones and others that the river has scarcely left dry. Indeed, the river still occupies a considerable number, though most of those now occupied are merely fragments. There are also a number of distributaries that are now drowned and are seen only in the bed of the river or on the floor of its estuary.

DISTRIBUTARIES NEAR TRENTON.

EARLY DISTRIBUTARIES.

Two very distinct distributaries that head on the higher ground about 2 miles southwest of Wyandotte or 3 to 4 miles north of Trenton are probably the oldest on the American side. The first of these begins in northeast sec. 36, in Ecorse Township, and after running for a mile southwest divides and passes around two sides of a knoll, forming an island more than a quarter of a mile long. The headward part of this channel is comparatively narrow and shallow and from its form appears to have been occupied for a relatively brief time. Its width averages from 200 to 300 feet and its depth from 5 to 10 feet. At the north line of Monguagon Township it turns and runs directly south for about a mile into southeastern Brownstown Township, where it turns southeast for another mile and enters the Detroit River about a mile south of Gibraltar.

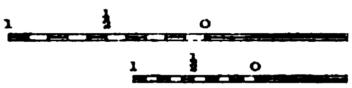
For the first 3 miles in Monguagon Township [1] this channel is broader and less sharply defined than it is in its headward part, the plain here being broad and flat. But in the western part of sec. 12 it is joined from the northeast by another distributary, which is better developed and more deeply eroded. The head of this channel opens near the north line of Monguagon Township in the northeast corner of sec. 6 about a quarter of a mile west of the Lake Shore & Michigan Southern Railway. At its head the channel is 12 to 15 feet deep and 50 to 75 feet wide, with steep banks and a narrow flat floor. It is not occupied in this part by a stream, but is wet and swampy. Within a short distance to the southwest a very small creek appears in it, but is lost in the reeds and has no perceptible flow at ordinary stages. In west sec. 12 this channel appears to merge with the channel from the north previously described. Another wide, ill-defined, shallow depression extends from this point southeast through south sec. 12 and east sec. 13, but seems to have been abandoned, for the channel which runs directly south is now followed by the small stream which drains both channels from the north. The tract of ground comprised in western sec. 12, southeastern sec. 11, and northeastern sec. 14 is nearly flat and the channels there have low banks and are ill defined. A small creek that comes into northwestern sec. 11 from the higher ground to the northwest shows no features of a distributary until it reaches the low, flat ground in north sec. 14, beyond which, south through Monguagon Township and southeast in Brownstown Township, distributary characters are fairly well developed.

From these facts it seems certain that this last channel, which lies close to the west line of Monguagon Township, was not a distributary in its upper part, but received a considerable volume of water while crossing the half mile of flat ground in northeastern sec. 14. Near the middle of sec. 35, Brownstown Township, this channel divides around a low knoll and reunites below in sec. 2. West of this knoll the western branch unites with the second main distributary from the north, and the united channel divides again around a sandy river bar in secs. 1 and 2 in the southeastward extension of Brownstown Township. This is a mile west of Gibraltar, a mile south of which the united channels enter Detroit River. A small creek which comes from the northwest through Brownstown Township strikes the divided channel in southwest sec. 35 and turns northward in it to join the creek that occupies the western distributary. A very faint distributary branches southwest in western sec. 26, Monguagon Township, and curves around through the eastern part of secs. 27 and 34 of Brownstown, but beyond this its course is uncertain. It may run through secs. 2 and 12 to Detroit River half a mile south of the distributary previously mentioned. In sec. 12 it is very well defined as a long, narrow marsh perhaps 30 to 40 rods wide. Another channel which runs through the center of sec. 12 is also well developed. The braided forms which the channels take in this locality are too complex for easy interpretation.

[1] Ecorse and Monguagon townships are irregular in plan, each taking two tiers of sections from the east side of the public-land townships next to the west. In each, therefore, sec. 1 lies next west of sec. 6.

Base from U. S. G. S. Wyandotte
atlas sheet.

MAP OF THE DIST



Distributaries

The distributaries thus far described have their headward openings at a relatively high level and must therefore have been among the first to be abandoned and were occupied for relatively short times.

The next distributary opens southwest about a mile north of Trenton. At its head the floor is now about 4 feet above the level of the river. It is larger than the distributaries just described, having a width of 400 to 500 feet on its floor. After passing the railroads it curves gradually south, passing about half a mile west of Trenton, and after running about due south through the east half of sec. 24 turns gradually southeast through sec. 25, where, within half a mile of Detroit River, it splits up into several smaller channels, some of which run southeast to the river, and some continue south, the main one to join the previously described channel about a mile west of Gibraltar. From this last two or three narrow, swampy channels turn southeast to Detroit River. This channel heads north of Trenton and may be called the Sibley channel, for the Sibley limestone quarries are near its headward opening.

In southwest Trenton another slight depression, evidently cut by a distributary stream, begins near the railroad station and extends for half a mile southeast to the channel behind Slocum Island.

CREASES.

Besides the large distributary channels in the vicinity of Trenton, a number of the peculiar crease type appear. (See p. 289.) The best occur between the larger channels near Trenton, particularly between the Sibley channel and Brownstown Creek southwest of Trenton. They may be seen from the train on any of the railroads running southwest from Trenton. These creases show the same peculiarities as those of St. Clair River (pp. 474–475), having narrow bottoms with no flat floors. They run in parallel lines 30 to 40 rods apart, curving gradually from south to southeast. The ground between them lies in long billow-like, smooth ridges with crests generally 10 to 12 feet above the troughs. Their surface is rather bowldery, suggesting moraines, and Sherzer has interpreted them as such.[1] But they are closely related to the general slope of the ground and change their courses with its changes in slope. Besides, they are related to the barrier which obstructed the river at this locality in precisely the same way as the creases near St. Clair; and the latter are certainly not moraines, but are transverse ridges left between early, immature lines of scour made by water currents flowing down the front slope of the main moraine of the Port Huron morainic system at the earliest stage of river flow.

LATE DISTRIBUTARIES.

At the south end of Trenton a remarkable channel a mile long separates Slocum Island from the mainland. It is about 500 feet wide and is floored by a marsh with aquatic plants. Its bottom lies so close to the level of the river that some water formerly passed through in high stages but not in low ones. The channel, which is now obstructed by a railway embankment, was evidently actively occupied for a very long time. Farther down the river a number of islands, evidently fragments of land left between a network of interlacing distributaries, are now at or slightly below lake level. These fragmentary channels and others that are clearly traceable below the present level of Lake Erie were made when the lake stood at least 12 or 15 feet lower than now. (See p. 462.) Many of these later distributaries have been submerged by the recent rise of the lake waters and the fragments of land between them appear now as islands. Humbug Island is one of these; Gibraltar and Snake Island, just west of Gibraltar, are others. Smaller ones are Calf, Horse, Big and Little Cherry, Oak, Sturgeon, and Peabody islands. These are separated from the mainland and from one another mainly by very shallow channels, 300 to 800 feet wide and in few places more than 3 to 4 feet deep. The water passing through them is not now effectively eroding. Indeed, many of these channels, especially those that are choked with reeds, are probably being slowly filled.

[1] Sherzer, W. H., Geological report on Monroe County, Mich.: Michigan Geol. Survey, vol. 7, pt. 1, 1900, pp. 134–135.

A number of channels around the south part of Grosse Isle show the same peculiarities as those along the west side of the river below Trenton. Celeron Island, half a mile southwest of the south end of Grosse Isle, is divided in two by a very distinct old channel 700 or 800 feet wide, now a marsh about at lake level, which starts at the north end of the island and runs south along its east side nearly half the length before turning southwest across it. At an earlier stage, with floor a little higher, this channel ran on to the south end of the island along its east side. Celeron Island stands out alone between channels now carrying 14 to 15 feet of water and this fragment of a distributary, so distinctly developed on the island in this isolated position, shows the remarkable changes that have taken place in this part of the river. This and many of the other distributary fragments lying within half a mile or so of the river are well shown on the newer charts of Detroit River issued by the United States Lake Survey. Hickory Island east of the south end of Grosse Isle is separated from the larger island by a shallow channel over a quarter of a mile wide. Elba Island is separated from Stone Quarry Island by one channel, and Stone Quarry Island from Grosse Isle by another which is now dry.

GROSSE ISLE NATURAL CANALS.

Several channels on Grosse Isle are wholly different from any of those on the mainland, being long and narrow and more like artificial canals than distributaries. The so-called Thorofare is the longest and most characteristic. This heads on the east side near the north end about due west of the south end of Fighting Island and runs south through the middle of the island down to the ferry road near the center, where it turns southwest and enters the Trenton branch of Detroit River at the Michigan Central Railroad bridge. The channel is 200 to 300 feet wide with no perceptible variation of width. It runs in a remarkably even course—nearly a straight line—for its whole length.

Until a few years ago the Thorofare was almost abandoned as a line of flow. It had only 1 to 3 feet of water in it, and Detroit River being a remarkably steady stream with very little variation of volume, the Thorofare became choked with water plants and was a favorite breeding place of mosquitoes. A few years ago the summer residents dredged a channel 4 or 5 feet deep and about 25 feet wide through its whole length and a current now flows through. The Thorofare is trenched 10 to 15 feet below the drift surface of the island.

At a point about a quarter of a mile east of its mouth another similar canal-like channel, called Frenchman Creek, branches from it and runs south to the extreme south end of Grosse Isle. This channel has not yet been dredged, but remains in its natural state, a swampy bayou.

Grosse Isle has also several much shorter channels of the same character. One branches from the west side of Frenchman Creek near its south end; another, half a mile to the northwest, separates Snake Island from Grosse Isle. The first of these is swampy but almost dry, and the second is still active though very shallow. Each is less than half a mile long. Another channel cuts into the west side of the island opposite Trenton. Except at its north end this one is now dry, but it formerly separated a small half-circular island from Grosse Isle. Another small channel of the same kind and about a mile long cuts across the north end of the island from northeast to southwest, with a branch nearly midway to the northwest. Two more short, narrow northeast-southwest channels cut across Point Hennepin. Those at the north end of Grosse Isle are on low swampy ground. Narrow, canal-like channels like these appear to be found in this vicinity only on Grosse Isle, though one or two short ones are said to have existed on Belle Isle, above Detroit, before the improvement of that island. Some of them seem like deepened creases. (See pp. 474–475, 489.)

When the level of the waters above Grosse Isle was a little higher a small distributary channel apparently led from the mouth of the south branch of Ecorse River to Monguagon Creek, passed close west of Wyandotte and Glenwood, and followed Monguagon Creek back to the river southwest of Wyandotte.

ROCKWOOD DISTRIBUTARIES.

West of the channel which terminates at Peabody Island (also called Sturgeon Bar Island on some maps) and which connects northward with Brownstown Creek several small, shallow, interlacing depressions run southward to Silver and Smith creeks and by their situation and relations to the area marked by distributaries just north of them appear to have been short-lived channels made by water coming from the north over the very low barrier which forms the divide between them and Brownstown Creek. They must have been very short lived because none of them are cut back to that stream; their heads all begin south of the divide along its southern side.

Farther west between these channels and Rockwood several troughs on the north side of Silver Creek and Huron River indicate still more faintly developed lines of flow from the north, but no such features appear west of Rockwood or south of Huron River, unless they lie in the great swamp back of Point Mouille, which has not been examined. The swampy channel which separates Peabody Island appears to extend south a little west of the shore to the swamp at the mouth of Huron River, and another swampy depression a quarter of a mile west of this extends over half a mile north.

These faint Rockwood channels have a very important bearing on the early history of Detroit River and of that part of the Lake Erie shore which formerly spanned it. (See p. 493.)

DISTRIBUTARIES NEAR AMHERSTBURG.

In some respects the most impressive of all the distributaries are those on the Canadian side southeast of Amherstburg. They are strongly developed and are longer and deeper than most others. One or two of them are drowned for long distances back from their mouths, making long estuaries or dead-water bayous. One of the most remarkable opens abruptly through the bank of the present river in the south edge of Amherstburg and may be called the Amherstburg distributary. Its floor was about a foot above the surface of Detroit River at the time of observation. At this point it is not over 200 feet wide, but its floor is wet and becomes a marsh within a quarter of a mile south. The Amherstburg distributary runs south-southeast for about a mile and then turns almost directly south and follows a slightly winding course to the shore of Lake Erie half a mile southeast of Bar Point, where it ends in a swamp which runs along the shore for about a mile behind a low ridge of dunes. From a mile south of Amherstburg the channel has a width of about 500 feet and carries from 6 inches to 4 feet of water.

At Elliott Point, about a mile south of Amherstburg, another small distributary runs southeast. It has two headward branches, one opening near the north range light and the other about 60 rods farther south. These two branches unite within about a quarter of a mile in a channel that crosses the Amherstburg distributary and about 1½ miles beyond unites with still another channel. The Elliott Point distributary is somewhat smaller than the Amherstburg channel and is not so deep.

About a mile east of Bar Point a short distributary heads less than a mile from the lake shore and enters the swamp behind the dune ridge. The general level of the ground is 5 to 6 feet above Lake Erie, and this short channel appears to have gathered its water from the flat area around its head.

The finest of the Canadian distributaries, however, lies about 1½ miles east of Amherstburg and runs south to Lake Erie. The backwater in this channel, giving it the appearance of an estuary, extends northeast of Amherstburg to a point about 5 miles from the lake, but the distributary characters extend to about 1½ miles north of the Michigan Central Railroad. Two headward branches meet about one-quarter of a mile north of the tracks.

This distributary had its headward opening at a level considerably above Detroit River. Its upper part was active only during the early part of the flow over the ridge, but its lower part probably received contributions from the Amherstburg and Elliott Point channels for a much longer time. The channel east of Amherstburg has a sufficient depth of water through-

out most of its drowned part to prevent its becoming choked with vegetation, although it generally has a fringe of reeds or lily pads along its margin. The water is said to be 5 or 6 feet deep east of Amherstburg, increasing to 10 or 12 feet toward its mouth.

RELATION OF EARLY DISTRIBUTARIES TO LAKE ROUGE.

It is interesting to note the relation of the earlier distributaries to Lake Rouge. The first two channels described above, having their heads on the higher ground southwest of Wyandotte, are the only two on the American side which had been abandoned by the time the water fell to the level of Lake Rouge. Indeed, it is not quite certain that the second or lower one, which heads in the northeastern part of sec. 6, Monguagon Township, was then abandoned, for the floor at its head is at about the same level as the beach. On the Canadian side the only one abandoned at that time was the long channel east of Amherstburg having its head on the high ground north of the railroad tracks. The largest channels developed at that time were two corresponding to the present main channels on the two sides of Grosse Isle. Into these the river appears to have sunk at a relatively rapid rate, until it uncovered the rock ledge and bowlder beds which offered effective resistance and held the water at the level of the first Rouge beach.

Running northwest from the Sibley quarry there is a broad, low divide with its crest close to 600 feet above sea level. Slight depressions in it having altitudes above 599 feet showed no enlargement such as result where distributaries were established, but depressions below this altitude did show such enlargements.[1] From this fact it is inferred that the new river first began to cut distributary channels on the obstructing ridge when the water surface north of the barrier had fallen to about 600 feet above sea level or 25 feet above the present river level.

The data for determining the level of the river surface at the time of the first cutting are not so satisfactory for the ridges at Detroit and St.. Clair. But as nearly as can be stated the water surface above the ridge at Detroit stood between 605 and 610 feet above sea level and at St. Clair close to 640 feet. It seems certain, therefore, that as the waters fell in the basin of Lake Erie and in the St. Clair-Detroit Valley the ridge at St. Clair was the first obstruction to be uncovered, that at Detroit next, and that at Trenton last. The cutting at St. Clair and Detroit and in the river bed above and below these points did not uncover any bedrock or other resistant material, so that the river cut down at a relatively rapid rate. Near Trenton, however, the river uncovered some resistant limestone and sandstone ledges, but chiefly a tough till thickly set with bowlders, mostly crystalline erratics brought there by the ice sheet. This is the character of most of the material that has been removed from the bed of the river in the recent deepening of the channel of the Limekiln crossing, where the original depth before dredging was 13 feet. The effectiveness with which this material resisted the erosion of the river was greater than present conditions would lead one to expect, for it is certain that the level of Lake Erie fell considerably very soon after Detroit River first began to flow and has only recently come back to its present level. The river must therefore have had more fall, and the rapids in the river, instead of being 2 or 3 miles long as now, must have extended several miles out into what is now Lake Erie. The current was probably more rapid at the crossing than it is now. It was the obstruction at the crossing, however, that determined the level of the water in the rivers above this point and in the basins of Lakes St. Clair and Huron.

DEVELOPMENT OF THE DETROIT RIVER ESTUARY.

DROWNING OF LAKE ERIE SHORE.

The shores of Lake Erie, especially the western shores, are distinctly drowned by the relatively recent backing up of the lake upon them. It seems certain, therefore, that the marshy shores near the mouth of Detroit River and the shallow offshores have not been cut

[1] At the time this area was being studied the marks of the topographic survey showing the altitude at every road corner were still fresh and afforded accurate measurements at two or three critical points.

back to any great extent by the lake at its present level. This applies to the west shore of the lake from the mouth of Detroit River to Toledo and to the Canadian shore for at least 4 or 5 miles east from Bar Point. But from Amherstburg south to Bar Point the land has been cut away in recent times. Whether this cutting has been done by lake waves or by river erosion or partly by each is difficult to determine, but for a mile or more south of Amherstburg it seems certain that the cutting has been done almost entirely by the river, for the shore is not much exposed to lake waves and the current is deep and strong. South of Elliott Point the most recent cutting has no doubt been done by the lake waves, but its amount has been slight. Originally the land here was probably cut out by the river when the level of the lake stood lower. When the lake stood 10 to 15 feet lower than now, the soundings indicate that the general shore line off Point Mouille and Bar Point must have been half a mile to a mile farther lakeward on both sides.

If the general trend of the coast line from Toledo to Point Mouille is produced it meets the Canadian shore somewhere near Bar Point, and if the line is curved a little eastward to conform to the general trend of the north shore, it will strike about a mile southeast of Bar Point and will then represent more truly the probable position of the shore line and the configuration of the land as they would have been if not modified by Detroit River.

The mouth or estuary of Detroit River may be defined as covering the area which lies between Grosse Isle and Bois Blanc Island on the north and a line joining Point Mouille and Bar Point on the south. It measures about 4 miles each way. There is much reason to believe that this area was originally land, like that now lying to the east and west, and had a surface substantially of the same character and altitude. In this area only one narrow channel near the east shore (the present line of navigation) is more than 20 feet deep, the depth over the rest of the area averaging about 10 feet. The bordering land is nowhere over 15 feet above the lake and on the west side is mostly under 5 feet. It is certain that at least a large part of the estuary was land, for Grosse Isle and in fact all the islands in this part of the river and also the banks of the mainland on both sides within the estuary are shown by the distributaries and the submerged channel beds to have been carved out of a former land mass by the river. But even granting this, the assumption that the whole area was formerly land may seem unwarranted.

This conclusion, however, is strongly suggested by the early distributaries. On the east side the distributaries ran away to the south from Amherstburg and one to the southeast from Elliott Point. This they would hardly have done if there had been anything like a deep channel running south from their heads on the course of the present river.

On the west side the distributaries east of Rockwood run south, which they could hardly have done if there had been an available channel between the present shore and Celeron Island. The river soon developed a master stream, or possibly two of them, one between Grosse Isle and Bois Blanc Island and another where the Trenton Channel is now, and these rapidly cut back channels in the relatively soft drift to the resistant rock ledges and bowlder beds. At this time, the level of Lake Erie being somewhat lower than now, the streams on the west side naturally turned southeastward toward it; and those which turned first had the shortest, steepest courses and drew an increasing proportion of the water to themselves, thus causing the Rockwood channels to be abandoned at a very early stage. It seems certain that these channels would not have been made at all, unless, when the water first rushed over the barrier, there was land with no pronounced channel or depression where the estuary now is. (See p. 491.)

In the estuary and along the near-by shores of Lake Erie the bottom is generally stony to a depth of about 15 feet, below which it is mostly sand. Possibly this might be ascribed to the action of the undertow from the surf with the lake standing at its present level, but in the light of other evidence this sand may be regarded as a submerged beach, due to the recent rise of the lake upon the land about all its western shores. Several authors pointed long ago to evidences of such a change, and Moseley (see p. 462) finds that the water has recently risen at least 12 to 15 feet upon the land, thus agreeing very closely with the amount of recent change suggested by the various features of the Detroit River estuary.

DROWNED DISTRIBUTARY CHANNELS.

Besides the distributaries described above, a number of elongated depressions on the floor of the estuary of the Detroit River, evidently the remains of former distributary channels now submerged, are very distinctly marked in several places and are traceable to a depth of 15 to 17 feet below the present surface of Lake Erie.

Southward from the vicinity of Humbug Island two narrow troughs lie in the river floor. One on the east side passes between Calf and Snake islands and Grosse Isle. The other one runs south from Humbug Island and turns gradually southeastward to the deeper water 2 or 3 miles from Horse Island. Another channel not so well defined runs south from the west side of Calf Island and with some breaks seems traceable almost as far as the other and is closely parallel with it. Both of these lead southward out of the present Trenton Channel.

On the east side of Grosse Isle there are several well-marked submerged channels. A very distinct one passes between Sugar and Hickory islands and is traceable for 2 or 3 miles to the south. Another passes just east of Sugar Island and within a half mile appears to branch into two parts which run southwest and southeast around the two sides of an extensive area of bedrock. Another larger channel lies west of Bois Blanc Island, where it divides in two, one branch going south and the other southwest to the channel east of Sugar Island. The main channel also divides north of Bois Blanc Island, one branch passing southwest to the channels just described and the other, which is the present main route of navigation, running south between Bois Blanc Island and the mainland at Amherstburg. A considerable part of these channels north of a line passing through the south ends of Hickory and Bois Blanc islands is more than 18 feet deep; on the west side between Humbug and Celeron islands a number of spots are deeper than 18 feet. All of these and many other details are well shown on recent issues of the United States Lake Survey chart of Detroit River.

The distributaries in the Trenton-Amherstburg district, including those submerged on the floor of the estuary, have been in process of making whenever Detroit River was flowing in full or nearly full volume. Twice, when this great volume was withdrawn, work on the distributaries must have ceased. The channels now submerged were made mainly before the recent rise of the waters of Lake Erie on its western shores, and the making of the estuary is intimately related to this earlier work of the river. The making of the distributaries has been accomplished in three high stages of the river. The first high stage was during the time of Early Lake Algonquin; during this stage all of the older, higher distributaries, including those east of Rockwood, were made and probably abandoned. The second high stage was during the Port Huron-Chicago stage of Lake Algonquin. The Algonquin uplifts occurred chiefly during this stage. The fact that so many clearly defined distributary channels pass 20 feet or more below present lake level and are submerged this much seems to show that the surface of Lake Erie was slightly lower than now during one or both of the earlier high stages, the present being the third high stage. The amount of difference is uncertain. It may have amounted to 20 or 30 feet at first, but toward the close of the Algonquin uplifts in the Port Huron-Chicago stage the water was brought very nearly up to its present level in the west end of the lake.

RECENT AND PROGRESSING CHANGES IN DETROIT RIVER.

Between Stony Island and Amherstburg and in the west channel between Trenton and Grosse Isle the bottom of the river is nearly everywhere stony. Two considerable areas of rock, one south and the other southeast of Stony Island, are covered by not more than 4 or 5 feet of water, and at some points by less. The trend of the main deep channel from its wider part north of Stony Island strongly suggests very recent change, and this is corroborated by the character and relations of the narrow deep channel between Bois Blanc and Amherstburg. The main channel from the north runs a little east of south to the Limekiln crossing, where it enters a majestic curve which bends around to the southwest and passes by the north end of Bois Blanc Island. West of the island it turns south, apparently in two branching courses. This channel appears to have been developed by a slow shifting eastward by erosion of the

eastern bank in comparatively recent times. At the time of Early Lake Algonquin the river could not have had this deep passage and have maintained the water at the level indicated by the Rouge beach, which is now 13 feet above the river at the head of Grosse Isle. But if the relatively deep channel at Limekiln crossing did not then exist, and if the river was held up partly by the ledges of rock in the vicinity of Stony Island, and if the shallow passages west of Stony Island and between Trenton and Grosse Isle were narrower than now, the former high level of the river is explained. At that time the Sibley and Slocum Island channels were no doubt active, but the channel east of Stony Island, now the main channel of the river, was probably not open or was small. The bedrock in the river slopes downward east from Stony Island and from the submerged rock ledges southeast of it. As the channel deepened and shifted eastward, it was pressed over against the Canadian shore and more and more of the river was drawn to it. The great curve which it made by cutting into the Canadian shore is exactly continued in the northeast-southwest line which forms the northern shore of Bois Blanc Island.

It seems certain that this gradual eastward shifting of the channel, with deepening and enlargement, has been the chief cause of the recent, post-Nipissing fall of the river and lake waters to the north. It was here on the Limekiln crossing and on the rocky ledges about Stony Island that the critical point lay. It was this obstruction which held up the waters of the Lake Huron basin during the south-flowing stages of Lake Algonquin.

Among the early distributaries one or two cut across to the south along a line passing a little east of Bois Blanc Island, where the main channel now is. This may have been the Amherstburg distributary (p. 491), and it may have included the north branch of the Elliott Point distributary. For a considerable time after the deepened channel between the Limekiln crossing and the north end of Bois Blanc Island had been established, the channel east of Bois Blanc remained undeveloped. Although much narrower than the passage west of the island and narrower even than the present Trenton Channel, the channel east of Bois Blanc is the deepest of all. That its development must have been relatively recent appears from its greater depth and narrowness, from the steepness of its banks at Amherstburg, and from the abrupt manner in which it departs from the great curve which the river had just previously developed. It seems quite certain, therefore, that its enlargement took place after the development of the great bend.

When the first dredging was undertaken by the United States Government in the shallow rapids at Limekiln crossing the greatest depth was 13 feet. On a line running west from Limekiln crossing the river was wide and shallow, with its deepest part in the newly excavated bend. The opening of the Amherstburg passage, with its greater depth and shorter distance must have increased the eroding power of the river at the Limekiln crossing, and with the deepening of these parts the water was lowered more or less in the shallow rapids to the west and in the Trenton Channel.

It seems probable that at the time of Early Lake Algonquin the channels west of Grosse Isle carried a volume of water as great or possibly greater than those east of it, but that the more effective erosion on the east side has established the main channel in its present course.

Several peculiarities of the present river are certainly very recent. The channel which passes down the east side of Fighting Island is as deep as the main channel west of the island but is much narrower. It appears newer than the main channel, especially from the fact that, although deep, its submerged banks are very steep, much steeper than those of the main channel. This channel is a short cut, and the water in it flows a little more rapidly than in the present main channel, and it will probably be gradually enlarged and eventually become the main channel.

When the river was somewhat higher than now the present Trenton Channel probably received its water in a shallow sheet over the flat grounds of northern Grosse Isle and of the vicinity of Wyandotte. The northern part of the Trenton Channel, which passes in front of the city of Wyandotte, was not then so deep as now. Its submerged bank is very steep, suggesting recent or present bank cutting.

DROWNED DISTRIBUTARY CHANNELS.

Besides the distributaries described above, a number of elongated depressions on the floor of the estuary of the Detroit River, evidently the remains of former distributary channels now submerged, are very distinctly marked in several places and are traceable to a depth of 15 to 17 feet below the present surface of Lake Erie.

Southward from the vicinity of Humbug Island two narrow troughs lie in the river floor. One on the east side passes between Calf and Snake islands and Grosse Isle. The other one runs south from Humbug Island and turns gradually southeastward to the deeper water 2 or 3 miles from Horse Island. Another channel not so well defined runs south from the west side of Calf Island and with some breaks seems traceable almost as far as the other and is closely parallel with it. Both of these lead southward out of the present Trenton Channel.

On the east side of Grosse Isle there are several well-marked submerged channels. A very distinct one passes between Sugar and Hickory islands and is traceable for 2 or 3 miles to the south. Another passes just east of Sugar Island and within a half mile appears to branch into two parts which run southwest and southeast around the two sides of an extensive area of bedrock. Another larger channel lies west of Bois Blanc Island, where it divides in two, one branch going south and the other southwest to the channel east of Sugar Island. The main channel also divides north of Bois Blanc Island, one branch passing southwest to the channels just described and the other, which is the present main route of navigation, running south between Bois Blanc Island and the mainland at Amherstburg. A considerable part of these channels north of a line passing through the south ends of Hickory and Bois Blanc islands is more than 18 feet deep; on the west side between Humbug and Celeron islands a number of spots are deeper than 18 feet. All of these and many other details are well shown on recent issues of the United States Lake Survey chart of Detroit River.

The distributaries in the Trenton-Amherstburg district, including those submerged on the floor of the estuary, have been in process of making whenever Detroit River was flowing in full or nearly full volume. Twice, when this great volume was withdrawn, work on the distributaries must have ceased. The channels now submerged were made mainly before the recent rise of the waters of Lake Erie on its western shores, and the making of the estuary is intimately related to this earlier work of the river. The making of the distributaries has been accomplished in three high stages of the river. The first high stage was during the time of Early Lake Algonquin; during this stage all of the older, higher distributaries, including those east of Rockwood, were made and probably abandoned. The second high stage was during the Port Huron-Chicago stage of Lake Algonquin. The Algonquin uplifts occurred chiefly during this stage. The fact that so many clearly defined distributary channels pass 20 feet or more below present lake level and are submerged this much seems to show that the surface of Lake Erie was slightly lower than now during one or both of the earlier high stages, the present being the third high stage. The amount of difference is uncertain. It may have amounted to 20 or 30 feet at first, but toward the close of the Algonquin uplifts in the Port Huron-Chicago stage the water was brought very nearly up to its present level in the west end of the lake.

RECENT AND PROGRESSING CHANGES IN DETROIT RIVER.

Between Stony Island and Amherstburg and in the west channel between Trenton and Grosse Isle the bottom of the river is nearly everywhere stony. Two considerable areas of rock, one south and the other southeast of Stony Island, are covered by not more than 4 or 5 feet of water, and at some points by less. The trend of the main deep channel from its wider part north of Stony Island strongly suggests very recent change, and this is corroborated by the character and relations of the narrow deep channel between Bois Blanc and Amherstburg. The main channel from the north runs a little east of south to the Limekiln crossing, where it enters a majestic curve which bends around to the southwest and passes by the north end of Bois Blanc Island. West of the island it turns south, apparently in two branching courses. This channel appears to have been developed by a slow shifting eastward by erosion of the

eastern bank in comparatively recent times. At the time of Early Lake Algonquin the river could not have had this deep passage and have maintained the water at the level indicated by the Rouge beach, which is now 13 feet above the river at the head of Grosse Isle. But if the relatively deep channel at Limekiln crossing did not then exist, and if the river was held up partly by the ledges of rock in the vicinity of Stony Island, and if the shallow passages west of Stony Island and between Trenton and Grosse Isle were narrower than now, the former high level of the river is explained. At that time the Sibley and Slocum Island channels were no doubt active, but the channel east of Stony Island, now the main channel of the river, was probably not open or was small. The bedrock in the river slopes downward east from Stony Island and from the submerged rock ledges southeast of it. As the channel deepened and shifted eastward, it was pressed over against the Canadian shore and more and more of the river was drawn to it. The great curve which it made by cutting into the Canadian shore is exactly continued in the northeast-southwest line which forms the northern shore of Bois Blanc Island.

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At Ecorse a bend, much like that above Amherstburg, has the same radius and slightly greater length, but is not so easy to explain, though it seems to be partly due to Ecorse River, which enters at this point, and partly to the fact that the undivided stream of Detroit River, since it sank to its present deep and relatively narrow bed, strikes the bank at this point with full force.

It is to be remembered that St. Clair River and the Detroit River above the head of the estuary flow at a slightly lower level to-day than they ever flowed before while carrying the full discharge of the upper lakes. It seems certain from this fact that their beds in the immediate past were not so deeply trenched as they are now, and this is the same as saying that they have been in recent times and almost certainly are still deepening and shaping their channels. These rivers bear many evidences of the fact that they are of recent origin. One is their straightness and the absence of any but very slight curves or meanders, like those of the Mississippi and other great rivers. (It must be remembered, however, that the Detroit and St. Clair rivers are not subject to floods and do not vary more than 5 or 6 feet between extreme stages, and are thus less likely to develop meanders.) The only features suggesting lateral cuttings and the development of meanders are the bends above Amherstburg, at Ecorse, and in the rapids at the head of the St. Clair River. This latter bend, however, is due to a different cause (p. 483).

The sinking of these rivers into their present narrow, constricted channels in clay is very recent. It is certainly not long since their courses were marked by shallow expansions which have now disappeared. Lake Rouge in particular is of this class and Lake St. Clair was much more expanded, mainly toward the east, south, and north. Almost the entire delta, as known to-day, was submerged when Lake St. Clair stood 3 feet higher. With the exception of the bowldery and partly rocky barrier at Trenton and Amherstburg, the entire course of these rivers is in soft sediments. If the resistant barrier west of Limekiln crossing had been absent the sinking of the rivers into the clay plain would have been more rapid. But the barrier yielded only very slowly and the rivers have in consequence got down into their present beds so recently that they have not had time to develop the normal characters of graded rivers flowing through soft sediments; lateral swing has barely begun to find expression. The cutting of the new Livingstone channel through the rock floor east of Stony Island will tend to lower the surface and increase the rate of flow and also the rate of channel deepening in the rivers above.

FLOODING OF TRIBUTARIES.

CAUSE OF FLOODING.

All the streams—even the very small ones—which are tributary to this connecting river system show certain characters which are abnormal and are not reconcilable with the ordinary course of stream development. Their mouths and lower courses are all drowned in precisely the same way as are the mouths of the streams that enter the western parts of Lakes Ontario and Erie. In the lakes the drowning was formerly supposed to be due entirely to recent uplift at their outlets, causing the water to back up and overflow the southwestern shores. But it is due also in considerable part to large increase in the volume of discharge at the outlet, amounting to 700 per cent, as shown on page 462.

The backing up of the waters in Lake Erie probably deadened the flow of Detroit River a little, but evidently only a very little, for gentle rapids still exist at the Limekiln crossing, and the river is lower and Lake Erie higher than formerly. The drowning in these rivers is due chiefly to the return of large volume after a long period of abandonment and very small volume. During the dry stage the river channels became long, narrow valleys, like the dry coulees of the West, but smaller and shallower, in which the small streams were lost. Meanwhile all the tributaries, great and small, worked away, deepening their beds to the lower base-level, which may be taken as the bottom level of the shallower parts of the great channels. The holes in the great river beds were probably ponds and the intervening stretches were swampy flats. The floor of the whole connecting river system was probably in this condition.

TRIBUTARIES OF DETROIT RIVER.

The evidences for this manner of development on the tributaries of Detroit River are clear. The United States Lake Survey charts show the depths in the lower courses of most of the tributaries on the American side. A few in which the soundings are not shown are well known to be overdeepened in their lower courses, the same as the others.

Ecorse River.—No soundings are given for Ecorse River, but its drowned condition is very evident on inspection and it is said by the inhabitants to be 12 or 15 feet deep for a mile or two above its mouth. The Ecorse is a small stream, its extreme sources lying at the western edge of Romulus Township about 14 miles west of its mouth. Within half a mile of its mouth it branches twice, and all three branches are drowned for half a mile to a mile above the point of junction.

Rouge River and minor creeks.—Rouge River, which is much the largest tributary of Detroit River, shows the effects of drowning nearly up to Dearborn, 9 miles above its mouth. Concerning the Rouge and the smaller drowned creeks where Detroit now stands, the following description was given by the writer[1] in 1897:

> One of the most interesting features in the vicinity of Detroit is found in the drowned condition of the lower courses of all the tributaries of the Detroit River. Even the smallest streams whose whole length is not over 2 miles have deep estuaries—much deeper than could have originated by their own erosion under present conditions. Many of these were navigable naturally and form excellent harbors for the smaller lake craft. There were several drowned streams originally where the city of Detroit now stands; among them were Parent, Savoyard, May, Knagg, and other creeks, while a little to the west of the city is the River Rouge, a larger stream, which shows the effect of drowning for some 8 or 9 miles above its mouth. About 3 miles above its mouth the Rouge receives a tributary from the north called Baby Creek. It is a very small stream, but it has a depth of 8 or 9 feet for nearly a mile from the Rouge, and it was here that Commodore Perry, after his great victory on Lake Erie in 1813, brought his fleet for repairs. Baby Creek itself has a small short tributary from the east which is navigable and a tract of land bordering upon it was set apart at an early day for a shipyard. Another very small tributary of the Rouge, about half a mile farther up, called Campbell Creek, shows drowning in a very marked way. The average midstream depth of the Rouge for at least 4 miles above its mouth is 18 to 20 feet. This is perhaps three or four times the depth that would be expected from erosion of the stream itself. The Savoyard was where the busiest part of the city is now located. There was a bridge across it at Congress Street where the depth of water was about 10 feet. This creek was the harbor of early Detroit, but with the growth of the city it became an open sewer and grew so obnoxious that it was finally covered over. Most of the other estuaries mentioned within the limits of the city have been filled up.

The Lake Survey chart shows depths mostly of 16 feet, with a few of 17 and 18 feet, up to the Michigan Central Railroad bridge 2 miles or more above the mouth of Rouge River. In 1897 the writer sounded from the bridge at Dix Avenue (now removed), 3½ miles above the mouth, and found a depth of 22 feet. At that time no dredging had been done on Rouge River above the River Street bridge, which is less than 2 miles above the mouth. Baby Creek was originally Baubee Creek, and some maps show Campbell Creek entering it from the west about a mile above the Rouge. Other maps, however, show Campbell Creek entering the Rouge just above the former Dix Avenue bridge. Some maps call this small stream Roulo Creek. At present Woodmere Cemetery occupies the western part of the old shipyard tract and the little tributary that received Perry's fleet is a stagnant bayou running through the middle of the cemetery. Above the city Conners and Fox creeks originally showed slight evidence of drowning, but they are both small and have now been straightened artificially.

Riviere aux Canards.—On the Canadian side the Riviere aux Canards is the only creek of importance. It enters about 3 miles above Amherstburg. No measures of its depth have been obtained, but it has the same drowned appearance as the other tributaries.

TRIBUTARIES OF LAKE ST. CLAIR.

Clinton River.—The only important tributary on the American side is Clinton River, which shows the effects of drowning up to Mount Clemens, about 6 miles above its mouth. Its average depth is 9 or 10 feet, with a few depths of 12 to 15 feet. Several small creeks that enter Anchor Bay from the north all show drowning.

[1] Some features of the recent geology around Detroit: Proc. Am. Assoc. Adv. Sci., 1897, pp. 201-202.

Milk River.—Milk River is a very small stream, but it shows pronounced drowning, as may be seen from the car on the electric line about 4 miles north of Grosse Pointe.

Southern tributaries.—On the Canadian side eight small creeks enter Lake St. Clair from the south, and all of them show drowning very clearly. No data as to their depths were obtained, but their condition is readily seen along the Grand Trunk Railway, which skirts the south shore.

Thames River.—The Thames is the largest tributary of Lake St. Clair. Soundings show depths of 18 to 22 feet for several miles from the lake, and it is navigable for small steamers to Chatham, about 16 miles above the mouth. Baptiste and Jeannette creeks, which enter the Thames on the south side near its mouth, are also plainly drowned.

Sydenham River.—Sydenham River enters the Ecarte Channel of the St. Clair delta about 6 miles above its mouth. At Wallaceburg, about 2½ miles above the channel, the two branches of the Sydenham meet and both show well-marked drowning. The south branch is navigable up to Dresden, 10 miles above Wallaceburg.

TRIBUTARIES OF ST. CLAIR RIVER.

Belle River.—For about 3 miles above its mouth Belle River resembles a deep natural canal. Its value as a harbor for small lake craft determined the location of Marine City at its mouth. Its general depth is 12 feet.

Pine River.—The lower mile or two of Pine River has a general depth of 12 feet and is an excellent harbor for small lake craft. This fact determined the location of St. Clair.

Black River.—Black River is considerably larger than the Pine and the Belle and for about 3 miles above its mouth shows depths of 10 and 16 feet. It is a typical example of an overdeepened and drowned stream.

Canadian tributaries.—On the Canadian side a few very small creeks, such as Talford Creek, a mile above Corunna, and Clay Creek, 3 miles above Sombra, seem to show (on the Lake Survey chart) slight drowning, but their condition has not been actually observed.

PROGRESS OF OVERDEEPENING AND DROWNING OR FLOODING.

During two periods, after the retreating ice sheet began to uncover the Great Lakes region, the upper three lakes discharged eastward from Georgian Bay, and Detroit and St. Clair rivers ran dry. During these two periods the relatively small local streams worked to a new and lower base-level and deepened their lower courses considerably.

FIRST DEEPENING.

Early Lake Algonquin had a comparatively short life, for the discharge soon left the Port Huron route and went to Kirkfield, Ontario, where it appears to have remained for a relatively long time. (See p. 410.) During this time some deepening at the mouths and in the lower courses of the tributaries may have been accomplished, but it is doubtful whether any recognizable evidence of it now remains. At the close of Early Lake Algonquin, St. Clair and Detroit rivers had probably only cut through the St. Clair and Detroit barriers and the softer parts of the Trenton barrier. They had not sunk into the deep beds in which they now flow.

The upper Algonquin beach and the first St. Clair and first Rouge beaches represent the water levels at that time. The general bottom levels of St. Clair and Detroit rivers were at that time probably not much, if any, below the present water surfaces of these rivers. During the third or Kirkfield stage of Lake Algonquin the beds of St. Clair and Detroit rivers were dry for a relatively long time. The first period of deepening was, therefore, to a higher base-level than the later one, for it was to the abandoned, immature, and only partly developed channel of the outlet of Early Lake Algonquin.

When the discharge of the upper lakes left Kirkfield it was probably divided in unknown proportions between two outlets, Port Huron and Chicago. The return of large volume to Port Huron drowned the lower courses of the channels which the tributary streams had cut to the dry beds, but the drowning effect was probably slight.

CHANNEL MAKING DURING TIME OF LAKE ALGONQUIN.

The later or main period of southward discharge of Lake Algonquin appears to have endured for a relatively long time, during which St. Clair and Detroit rivers must have greatly eroded their beds, probably enough to bring their level down to that now marked by the Nipissing beach at the south end of Lake Huron and to correlative levels descending, as in earlier stages, by steps toward the Trenton barrier and the basin of Lake Erie. During this relatively long period of flow with large volume the connecting channels were probably cut down nearly to their present depths, and the way was prepared for the deepening of the beds of the tributaries in the next period of abandonment.

SECOND OR LAST DEEPENING.

The closing stages of Lake Algonquin were marked by the retreat of the ice and the opening of a passage eastward at North Bay, Ontario, by which the upper lakes discharged through Mattawa and Ottawa rivers to the sea. This event left St. Clair and Detroit rivers dry again, and it was chiefly then that the tributaries accomplished the deepening now shown in the drowning of tributary beds that appear to have been overdeepened. They cut to a base-level about 30 feet lower than that which had controlled them when the great channels were last carrying large volumes. It is to be remembered that at the close of the Port Huron-Chicago stage of Lake Algonquin the level of the waters in the south end of Lake Huron was about 15 feet above present lake level, somewhat less in the basin of Lake St. Clair, and still less in that of Lake Rouge. Cole [1] found buried peat beds in the St. Clair delta 14 or 15 feet below the present level of Lake St. Clair, so that 30 feet or perhaps a little more may be regarded as a close measure of the drop in base-level which affected the tributaries when the great rivers last ran dry.

These facts might afford a basis for a rough estimate of the time which passed between the second abandonment of the outlet at Port Huron and its reestablishment when North Bay was elevated. This interval, whatever it might be, would also measure the time during which the upper lakes discharged past North Bay to Ottawa River—the duration of the Nipissing Great Lakes. But it would hardly measure the transitional or two-outlet phase of those lakes, for in that phase more or less of the discharge had returned to the southward course and the deepening grew less. It is possible that results having considerable value as a check on other means of estimation might be obtained in this way.

During the time of the Nipissing Great Lakes the streams which gathered in the abandoned connecting channels appear to have reversed the direction of flow, going northward to Lake Huron. It seems probable that all the tributaries, including even the Ecorse and the Riviere aux Canards flowed northward to the basin of Lake Huron rather than to that of Lake Erie, which was so much nearer. This stream may be called Algonac River. This direction of flow seems the more probable when it is remembered that the original depth on the Limekiln crossing before dredging was only 13 feet and that that depth had almost certainly been attained only in very recent times. The cutting of the bank on the Canadian side at the Limekiln crossing is still going on. When the bank at this place stood 2,000 feet farther west than now the greatest depth on the crossing, supposing the water surface to remain as it is now with reference to sea level, would be only 8 or 9 feet. In the Trenton Channel the present least depth is 13 feet, about 3,000 feet south of the railroad bridge. The bottom is marked "stony" on the charts, not rocky, so that the depth here has probably been increased in recent time. It may be inferred from these facts that just before the great volume returned the lowest bottom surface on the barrier was at least 5 feet higher than now, and of course the water surface was at first slightly higher.

The only obstacle to the supposition that all these streams flowed northward at that time is the present shallowness of the water at the mouths of the distributaries of the St. Clair delta.

[1] Cole, L. J., Michigan Geol. Survey, vol. 9, pt. 1, 1903.

But it might easily have happened that one among the several distributaries then existing should have afforded a lower passage than that over the barrier above Amherstburg.

Spencer notes the depth of 90 feet in the north channel of the St. Clair delta, a little south of Algonac, and takes this as an indication of a northward-flowing stream, and in order to have a northward gradient from this point, supposes the contemporary beach north of Point Edward to be at least 110 feet below present lake level. But, as has been pointed out above, this assumption and the interpretation on which it depends are not justified by sound theory. Some of the deep holes in Mississippi River above New Orleans are 150 feet deep, but to account for this it is not necessary to suppose that the Gulf of Mexico once stood 180 or 200 feet lower than now. Deep holes of this kind in great rivers flowing in alluvial or other soft sediments are common enough and their cause is well known. All of them are in bends where the current is swift and is strongly deflected against the concave bank. The deepest holes in Rouge and Clinton rivers as well as the one south of Algonac stand in this relation. They are not relics of a past condition but are made by the rivers as they are to-day. It is not these exceptional deep holes that constitute evidence of deeper erosion in the past, but the average depth of the lower courses of the tributary streams.

As shown on the charts, the present distributary channels in the St. Clair delta have depths ranging commonly between 25 and 50 feet, and at their extremities the North and South channels have least depths of 8 and 10 feet, respectively, not counting the artificial canal. It seems scarcely possible to explain the overdeepening of the tributaries of Detroit River and Lake St. Clair except by northward drainage from the barrier at Amherstburg through some one of the distributaries in the St. Clair delta.

Sydenham River stood in a different relation to the delta, for it enters the Ecarte distributary 6 miles above its mouth and it is only at their mouths that the distributaries grow shallow. It would seem certain therefore that the Sydenham at that time went northward. But this and the other tributaries of St. Clair River show no more effects of drowning than do the streams farther south; indeed, they show less, for a reason given below.

PRESENT DROWNING OR FLOODING.

When the transitional or two-outlet stage of the Nipissing Great Lakes ended and the pass at North Bay was uplifted above that at Port Huron, the great outlet river returned once more to a southward course and the abandoned beds of St. Clair and Detroit rivers and Lake St. Clair were refilled and the enlarged mouths and lower courses of all the tributaries were drowned. That was the beginning of the present condition; there have been no changes of outlet nor any notable change in volume since that time. The level of the lake waters was then about 15 feet above the present level at Port Huron, 9 or 10 feet above Lake St. Clair, and 6 or 7 feet above the present river between Detroit and Grosse Isle. Hence, the drowning effect, as it appeared at the first return of the large river, has been considerably reduced by the lowering of the river surface. This is especially true of the tributaries of St. Clair River, where this lowering has amounted to 12 or 15 feet, but the amount is progressively less in Lake St. Clair and Detroit River. This accounts mainly for the somewhat greater amount of drowning seen now in the Rouge and the Thames as compared with Black River at Port Huron. The lowering of the river surfaces has been due to the recent erosion of the barriers and of the river beds—to the gradual sinking of the great connecting rivers more deeply into the soft sediments of the plain; and, as already said (p. 499), the amount of this deepening (to which drowning now gives the effect of overdeepening) might be taken as a measure of the time during which the southward discharge was absent.

Other factors, however, such as lowering of the river level and silting up or aggradation of the overdeepened parts, operate to reduce the apparent deepening and complicate the calculation. Each tributary has been bringing more or less sediment to its drowned lower course ever since the great volume returned. The finer parts are partly deposited in the estuary and are partly carried into the larger river. Sand and gravel are deposited in the heads of the estuaries, where the first deep water is met, and are gradually accumulating as inset delta deposits. It is interesting to note that the amount of this refilling with sand and gravel

is too small to be noticed in the smaller streams, and is smaller than would be expected in most of the larger streams, such as the Rouge, the Clinton, the Thames, and the Sydenham. Black River alone shows a large amount of refilling, but apparently with more reason. The other streams flow through a gently sloping plain for a longer distance, and so have lower gradients and gentler currents for longer distances above their mouths. Black River cuts through the Port Huron morainic system at Wadhams, from near which the refilling extends to within about 3 miles of the mouth of the river. The river flows in a valley trenched deeply in the drift for several miles above and below Wadhams. Its valley is older than the time of Algonac River, but it was deepened at that time up to a point near Wadhams. The deepened part is now floored with a flat gravel deposit or an elongated estuarine delta, which constitutes the present flood plain and is gradually extending downstream. The amount of this refilling might be made the basis of a rough estimate of the time since the discharge of the upper lakes returned to Port Huron. For this, however, other and much better data (Niagara Falls and Gorge) are available, and the amount of refilling would be interesting chiefly in its relation to that better-determined estimate.

A large part of the surface of the St. Clair delta is now above the water; its head near Algonac is about 6 feet above. The water surface in the south end of Lake Huron and in the head of St. Clair River has fallen about 15 feet since the end of the transitional stage from the Nipissing Great Lakes; at Algonac it has fallen slightly less, so that at the beginning of the present stage the water was probably 6 or 7 feet deep over the ground at the head of the delta. Hence, the emergence of the St. Clair delta in this last stage of the lake history is relatively recent, and the development of the present distributary channels in it is nearly as recent, the necessity for their existence arising only when the water began to grow thin over the surface of the delta.

A large part of the westward crowding of the rapids at the head of St. Clair River, causing the erosion of its western bank and the accretion of gravel on its eastern bank, is also relatively recent, and has resulted in a lengthening of the rapids and the bend and a large increase in the gravel deposit at the head of the river.

Six principal changes are now going on: (1) The two great rivers are gradually deepening their channels; (2) they are beginning to develop lateral swinging and bank cutting, as where Detroit River is cutting into the Canadian bank at the Limekiln crossing; (3) the lowering of the river surface is decreasing the area of Lake St. Clair and the effect of drowning in all the tributaries; (4) the tributaries are filling and aggrading their drowned parts with sediments; (5) the St. Clair delta is growing and filling up Lake St. Clair; and (6) the spit gravels at the head of St. Clair River are growing westward and pushing the river farther into the land on the west side.

RELATIVE AGES OF THE CONNECTING RIVERS.

St. Clair River came into existence first and Detroit River almost at the same time; then came the Niagara River; then, in all probability, the upper part of the St. Lawrence below Lake Ontario, extending perhaps down to Cornwall; then the upper part of Nipigon River (the part above the long rapids), and finally, about coincidently, the lower part of the Nipigon, the lower part of the St. Lawrence, and the whole of the St. Marys between Lakes Superior and Huron. The three last-named rivers are very new in their lower courses, and if differential elevation is still in progress it is lifting their mouths out of the water and making their beds shallower and longer.

CHAPTER XXV.

DEFORMATION OF SHORE LINES.

By Frank B. Taylor.

POSSIBLE CAUSES.

Old shore lines may have been deformed in several ways.

1. The water surface may not have been perfectly horizontal while the beaches were being made, as where the water of a lake rested against the front of the ice sheet and was drawn up toward it by the gravitative attraction of the ice. This effect was slight in the Great Lakes region but was always present.

2. Shore lines may be deformed after they are made by elevation or depression of the land arising from one or more causes.

According to the theory of isostasy the larger inequalities of the earth's surface express differences of density of segmental parts of the earth, the less dense high or continental parts being balanced against the more dense low or oceanic parts. As a sequence of this theory, erosion from the land surface removes weight from that part and deposition of sediment in the sea adds weight there, and on account of this shifting of weight the equilibrium of the parts affected is progressively disturbed. The deposition of sediments causes the ocean floor to sink and erosion of the land causes the continental areas to rise. De Geer has ascribed the rising of the land and consequent deformation of shore lines of Sweden in part to the erosion of the old (pre-Cambrian) land surface, and he extends the same idea to America.

A popular view, in some sense a corollary of the theory of isostasy, is that the earth movements which raised and deformed the old shore lines were due to resilience of the land following depression by the weight of the ice sheet. There are many reasons for regarding this idea with favor, and it has found more adherents than any other among students of glacial geology.

All forms of earth movement, without regard to cause, may deform old shore lines. This includes the movements involved in continental and mountain growth as well as the more local warpings, sinkings, and upheavals.

3. Eustatic movements, like those described by Suess, tend to raise or lower the whole ocean with reference to the land. Such movements would cause the shore lines to be submerged as though the land were depressed, or abandoned as though the land were elevated, according as the movement of the sea was positive or negative.

Shore lines may also be in effect raised or depressed (according to Suess) by oscillations of the ocean which may at one time cause an actual excess of water at the poles and an actual deficiency at the equator, and at other times may reverse these conditions, producing the effect of raised and submerged shore lines in both high and low latitudes.

All these possible causes should claim attention in any exhaustive discussion of the subject. In this monograph, however, it will suffice to consider a few of them in a general way.

HINGE LINES AND AREAS OF UPLIFT.

The map (fig. 14) is diagrammatic and is intended to show only the principal facts relating to the ice sheet and the uplifting movements. The boundary of the last or Wisconsin ice sheet at its greatest extent is marked by the heavy line extending entirely across the map, and defines by its sinuous course the outlines of the several strongly marked lobes and reentrant angles of the ice front. The Dakota and the Minnesota-Iowa or Iowa lobes are sharply developed in the west. Between the northeast angle of the Driftless Area in Wisconsin and

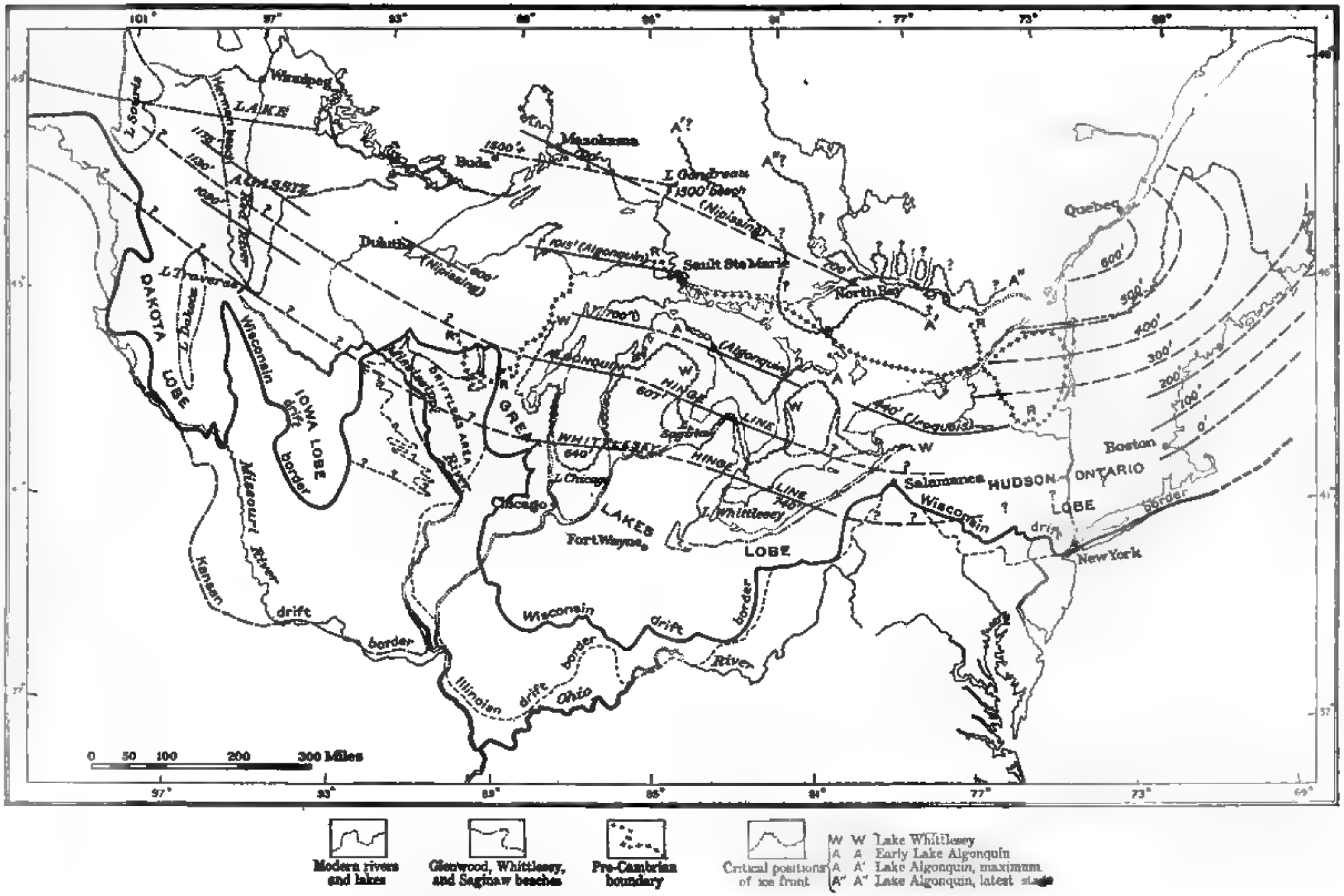

FIGURE 14.—Diagrammatic map showing the relation of the Whittlesey and Algonquin hinge lines to the extreme border of the Wisconsin ice sheet, with three later critical positions of the ice front and several of the isobases. The hinge lines and isobases in the regions east and west of the Great Lakes are added to show the general relation of the deformations in those parts to that in the region discussed.

the reentrant angle at Salamanca, N. Y., a great ice lobe, 600 miles broad at its base, which may be called the Great Lakes lobe, projected 400 miles southward. In it were merged the Lake Erie, Lake Huron, and Lake Michigan lobes and a number of lesser subsidiary lobes, like that of Green Bay in Wisconsin and Grand River valley in eastern Ohio. The remainder of the lobe, projecting south of a line joining Chicago, Ill., and Mansfield, Ohio, was shaped like an inverted cauliflower. East of Salamanca a broad, flat lobe reached the islands south of Cape Cod and had an ill-defined apex in New Jersey just west of New York City. This may be called the Hudson-Ontario lobe, for it was formed chiefly by ice diverging featherwise from the axis of the Hudson-Champlain trough and was augmented on the west by ice spreading southward from the eastern part of the basin of Lake Ontario.

The region west of the meridian of Duluth is included simply to show how the features there are related to those of the Great Lake region.[1]

No shore lines are shown in the Great Lakes area except the Glenwood or highest beach of Lake Chicago, the Whittlesey beach, and the correlative beach of Lake Saginaw.

Two hinge lines are shown. The first or Whittlesey line crosses Lake Erie from Ashtabula, Ohio, through the middle of Lake St. Clair and thence bends more to the west, crossing Lake Michigan west of Grand Rapids. This line is the isobase of zero for the first or earliest recognized uplift recorded by the beaches. South from this line the Whittlesey and lower beaches and the beaches of Lake Chicago are horizontal and give no evidence of having been uplifted or tilted. But at the hinge line the Whittlesey and Glenwood beaches begin to rise northward. The horizontal part of each successive beach below the Whittlesey reaches a little farther north than that of its predecessor before beginning to rise, but all of them rise before reaching the Algonquin hinge line. The successive positions of the hinge line are shown with approximate accuracy in figure 15.

The Algonquin hinge line is the isobase of zero for the Algonquin beach. South of this line the Algonquin beach in the Lake Huron and Lake Michigan basins is horizontal, but at the line the beach begins to rise northward. On the map the Algonquin hinge line is produced conjecturally eastward across Lake Erie and is made to turn toward the east in harmony with the 440-foot isobase of the Iroquois beach. The conjectural eastward extension of the first hinge line is also bent in the same way and for the same reason, where it crosses the unglaciated reentrant angle south of Salamanca. Both hinge lines are also produced conjecturally northwestward to the region of glacial Lake Agassiz. The highest or Herman beach of that lake rises northeastward a little, even at the extreme south end of the lake, but Todd found Lake Dakota to be horizontal. The first hinge line is therefore drawn through Traverse Lake parallel with the isobases for 1,090 and 1,175 feet, both of which are based on accurate measurements made by Upham.[2] The Algonquin hinge line is drawn parallel with these isobases and is placed where the earlier uplift is about the same in amount as it is at the Algonquin hinge line on the "thumb" of Michigan. The Algonquin isobases for 700 and 1,015 feet are shown and the general harmony of their trend with the two hinge lines and with the western part of the 440-foot isobase of the Iroquois beach is evident. All the lines run west-northwest over Lakes Huron, Erie, and Ontario, bend more westerly over Lake Michigan and the eastern part of Lake Superior, and return to west-northwest toward Lake Agassiz. The 440-foot isobase of the Iroquois beach bends sharply east near Rochester, N. Y.

Two isobases of the Nipissing beach are shown. This beach comes down to the level of Lake Superior (600 feet above sea level) at the head of Ashland Bay and its nodal line runs about N. 65° W. from this point. The hinge line of this beach is at an altitude of 596 feet in the Lake Huron and Lake Michigan basins, but its place in Lake Superior has not been determined. The isobase of North Bay (700 feet) is the most northerly yet determined. (See p. 460.) In the basin of Lake Superior the trend of the Nipissing isobases is quite different from the Algonquin. In the basins of Lakes Michigan and Huron the Nipissing beach appears

[1] The shore lines of the glacial lakes Agassiz, Souris, Dakota, and Minnesota are taken from Warren Upham's maps in his monograph on glacial Lake Agassiz (Mon. U. S. Geol. Survey, vol. 25, 1896).

[2] Op. cit., pp. 278–381.

to hinge on the same line as the Algonquin, but this is probably not the case at the west end of Lake Superior. The isobases of the Algonquin and Nipissing beaches are shown more completely in figure 8 (p. 439) and figure 9 (p. 461).

The beach observed by Coleman at Gondreau Lake north of the east end of Lake Superior has an altitude of about 1,500 feet. A conjectural isobase is drawn from this place to a point

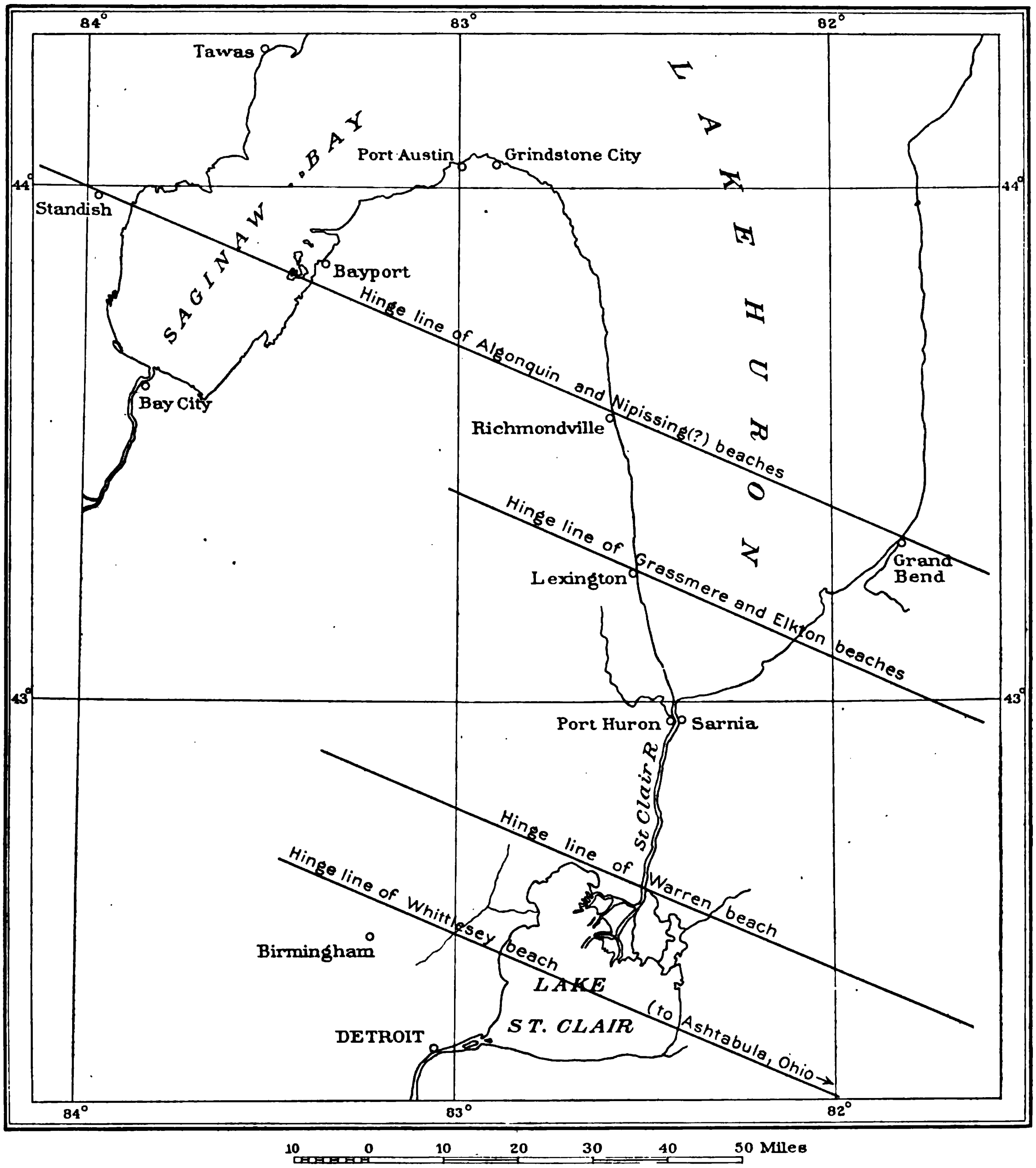

FIGURE 15.—Map showing northward shifting of the hinge lines.

north of Buda, 40 miles northwest of Port Arthur, where in 1895 the writer observed a well-defined upper limit to extensive lake sediments.

Besides the extreme border line of the Wisconsin ice, four later positions of the ice front, corresponding closely to critical times in the uplift, are shown in figure 14. The first position, WW, is that of the main moraine of the Port Huron system, and marks the position of the barrier

of Lake Whittlesey. The second position, AA, is that of the ice barrier of Early Lake Algonquin. The third position, A'A', which marks the place of the ice front when the lake was at its greatest extent and the upper group of beaches had reached their farthest northward extension, and the fourth position, A''A'', which marks the place of the ice front at the last stage of Lake Algonquin (the lower of the Fort Brady beaches) just before the inauguration of the Nipissing Great Lakes, are only rough approximations, the actual position of the ice front having not yet been well determined.

The curved isobases in the region south of St. Lawrence River and east of Lake Ontario show present knowledge concerning the deformation of the marine shore line, as recently represented by Goldthwait.[1] These lines have no connection with the glacial lakes, but relate solely to the marine waters. They are added merely to show the general relation of the deformation in the marine area to that of the Great Lakes region.

ICE ATTRACTION.

The effects of ice attraction in deforming the old beaches are discussed on pages 343–348.

RESILIENCE FOLLOWING DEPRESSION BY ICE WEIGHT.

RELATIONS OF UPLIFT TO RETREAT OF ICE.

The causes that deformed the old shore lines of the Great Lakes region acted within fairly well defined limits of space and time; that is to say, although the deforming causes affected a vast area of the northern and northeastern parts of the continent, they had clearly defined southward limits in the region of the Great Lakes, and the time of their action is recorded in the deformed beaches of a long series of lakes and lake stages covering almost the entire period since the maximum of the last or Wisconsin ice sheet. The areal relations of these limits to the area covered by that ice sheet and the time relations of the uplift to the retreat of the ice are so nearly in accord that to many minds they prove causal relation between the ice sheet and the elevation of the land. The apparent great strength of this explanation is not denied, but serious difficulties, that ought not to be overlooked, stand in its way.

The southern boundary of the uplifted lands, marked by the first or Whittlesey hinge line (see fig. 14), is roughly parallel to the boundary of the Wisconsin ice sheet and is not far north of the mean course of that boundary from northwestern Dakota to the Atlantic coast in Massachusetts. Further, the Algonquin hinge line is substantially parallel with the first, the interval between them, however, being about twice as wide in the west as in the east.

The attitudes of the old shore lines show three distinct periods of land elevation in the Great Lakes region, separated by two fairly well defined times of stability. The relations of the uplifting movements to the retreating ice sheet may be briefly summarized as follows:

1. The first elevation began when the ice front had retreated nearly halfway across the Great Lakes region. Just before this uplift the ice front had been resting on the main moraine of the Port Huron system, which marks the ice barrier of Lake Whittlesey. This position of the ice front (see wavy line WW in fig. 14) has been traced continuously through nearly the whole length shown. The uplifting movement continued in spasmodic fashion until the ice front had retreated nearly to the position marked AA. During this interval the hinge line kept shifting north. This movement deformed all the beaches before the Algonquin, the Maumee to the Lundy, inclusive.

It is entirely possible that uplifts occurred before the formation of the earliest glacial lakes and hence were not recorded in the beaches. The Lum and Rochester channels seem to show a movement occurring just after these channels were abandoned, but the beaches show none that are clearly discernible. The movement, if it took place, must have been relatively slight and could have extended only a few miles, if at all, south of the Whittlesey hinge line.

2. At the position AA the ice barrier was holding up the water of Early Lake Algonquin. But this short-lived stage soon gave place to the longer second stage with outlet at Kirkfield,

[1] Bull. Geol. Soc. America, vol. 22, 1911, pp. 723-724.

Ontario, and from the beginning of that stage until the ice front had retreated approximately to the position A′A′ no uplift occurred.

This conclusion is supported by the fact that the upper group of Algonquin beaches (see pp. 415, 433) extend to the northern highlands of the lake region, reaching 1,220 feet on the hills north of Trout Creek, Ontario, 25 miles south of North Bay, and about 1,500 feet (as observed by Coleman) at Gondreau Lake, north of Lake Superior. These high beaches have not been continuously traced to the beaches farther south, and their places in the group are not definitely known; but they are strong and show characteristics that indicate the work of heavy waves of wide waters, and their altitudes agree in a general way with the planes of the upper members of the upper group produced.

3. When the ice front was approximately at the position A′A′, the second and greatest period of uplift began. It was this movement that produced the remarkable deformation of the Algonquin beaches and caused the northward splitting that amounted to 365 feet at Sault Ste. Marie to 550 feet near North Bay, and apparently to 850 or 900 feet at Gondreau Lake, 150 miles north of Sault Ste. Marie.

The relative rapidity of the middle part of this uplift is remarkable. By the time the ice front had retreated from the position A′A′ (fig. 14, p. 503), approximately to the position A″A″ (about 150 miles on the lowest line of retreat), the greater part of the Algonquin uplift had been completed. That for a considerable time the movement must have been relatively slow is shown by the great strength of the beaches of the upper group. That all the movements turned on the Algonquin hinge line shown in figure 8 (p. 439) and figure 14 has been established by the wye-level surveys of the beaches made in 1907 and 1908 by Goldthwait and the writer. From Mackinac Island, Mich., and from Kirkfield, Ontario, all the numerous beach ridges of the Algonquin groups were found to converge southward to this one hinge line.

4. The most characteristic quality of the Nipissing beach is its great strength and relatively mature development, which seem to show stable condition of the land. The beach is stronger near the Mazokama-North Bay isobase than elsewhere, but it is strong for a long distance south of this line; so far south, indeed, that some part of its strength should probably be attributed to the two-outlet stage when the overflow was divided between Port Huron and North Bay. These characters seem to imply either stability or extremely slow uplift. Hence, during the time of the Nipissing Great Lakes and perhaps for a time during their closing two-outlet stage, the elevation of the land had ceased or was extremely slow. This period covered the time of the retreat of the ice from the position A″A″ and may have included the entire disappearance of the Labrador ice sheet.

5. Finally, the movement of elevation was renewed and has continued rather slowly and spasmodically to or nearly to the present time. In this time North Bay has been uplifted a trifle more than 100 feet and the lands farther north still more. This period may possibly include the last fading stage of the ice sheet, but in all probability it began after the complete disappearance of the latter.

In the marine area in the east it is not yet possible to divide the time of the uplifting movements into periods corresponding to those so clearly defined in the Great Lakes region. From Boston to Quebec the isobases shown on the map range from zero to 600 feet. It seems significant that the first hinge line of the Great Lakes region, if bent in harmony with the 440-foot isobase of the Iroquois beach and produced eastward, seems naturally continued in the zero line of the marine area. There seems to be no reason to doubt that this apparent relation represents the real relation. It can not be safely inferred, however, that the isobases shown around Quebec record the whole amount of uplift that has affected that region, for, as in the Great Lakes region, the early uplifts raised a large area of the land still covered by ice, along with a part of that which had just been uncovered. Thus, the lands for 100 miles or more south and east of Quebec may have been and probably were elevated several hundred feet while still covered by the ice sheet. It follows that the marine beaches observed near Quebec and along the south side of the St. Lawrence probably belong to a different and later period from those near Boston. It may at some time become possible to recognize stages of uplift

and correlative ice fronts and beaches in the marine region, but data for doing so are not yet available.

In the Great Lakes region the first period of uplift raised the Warren beach at Bad Axe, Mich., about 100 feet above the level of that beach in the area of horizontality. Bad Axe was not far outside the front of the ice as it then stood, and it seems certain that the uplift involved much land that was still under the ice sheet. No correlative beaches and moraines found in the deformed area show diminution of uplift on approaching the front of the ice and some of them show increased northward rise, even after allowing for ice attraction. Indeed, it seems probable that the whole area of Lake Algonquin and perhaps much more was uplifted at least 100 to 150 feet by the first movement while still covered by the ice sheet. This occurred before the beginning of Lake Algonquin and requires the addition of some such amount to the total uplift recorded in the Algonquin beach in the northern part of the Great Lakes region.

THEORETICAL PRINCIPLES.

On its theoretical side the relations of ice weight to land depression and resilience present many difficult problems. Some of the most important elements that must enter into any attempt at numerical evaluation have not yet been satisfactorily determined. One such element is the thickness of the ice over a given locality or area at a given time. It seems certain that it will be possible some day to determine this with a close degree of accuracy, but at present all estimates are uncertain.

According to Lane the weight of the ice sheet might depress the land in two ways—by elastic compression and by actual transfer of fluid or plastic molten magma in relatively large quantities from one place to another beneath the earth's crust.

Woodward[1] has shown that one atmosphere of pressure on the earth's surface tends to shorten the earth's radius about 2 meters. This furnishes the required datum for estimating the amount of depression due to elastic compression under the weight of the ice.

On the basis of this hypothesis Lane[2] estimated the proportion of the total depression that might be ascribed to each of these two modes of adjustment on the assumption of certain conditions of ice thickness which he thought applicable to a particular area in Michigan. He points out that 2 meters of compression by one atmosphere of pressure means that an ice or water load on the surface would tend to compress the earth underneath by about one-fifth as much as the thickness of the water or ice.

On the assumption that the earth's crust is a somewhat flexible sheet resting on a more or less fluid interior, Lane shows that the weight of the ice or water would bend the crust down into this fluid interior and that, neglecting for the time the lateral or shearing stresses, the depression would be accomplished by the displacement of an equal weight of the magma or fluid rock beneath the crust. The density of the rock below being approximately three times that of water, the amount of depression would be about one-third of the thickness of water or ice. The use of this ratio without qualification implies the assumption that the relation is truly and simply hydrostatic, that the interior fluid has no physical quality which prevents it from obeying hydrostatic laws with substantially complete fidelity, and therefore that viscosity in such degree as is allowed for the interior fluid of the earth is no bar to interior readjustments of mass in strict accordance with hydrostatic laws.

Lane's assumption that resilience may be caused by the hydrostatic inflow of a fluid molten magma previously displaced by depression of the earth's crust seems to the present writer out of accord with the best modern conclusions regarding the conditions of the earth's interior. Years ago the physicists gave the geologists reason enough for believing the earth to be solid to its center and to have there its greatest density and a rigidity greater than that of steel; and the more recent records of the propagation of earthquake waves through the deeper parts of the earth seem, through many repetitions, to have fully established its essentially solid, rigid character. Again, though some physical phenomena affecting the earth find no bar to

[1] Bull. U. S. Geol. Survey No. 48, 1888, p. 66; Sixth Ann. Rept. U. S. Geol. Survey, 1885, pp. 295-296.
[2] Personal communication, Nov. 9, 1907.

their action in mere vastness of area or of matter involved, the transfer of tremendous volumes of fluid magma through great distances beneath the earth's crust is not of this class. The difficulty of explaining such a transfer is enormously increased when a mass of magma from 1,000 to 4,000 feet thick and underlying about one-third of the continent of North America is involved. The displaced magma could go nowhere without producing effects that would be readily recognized. With the amounts and the distances so great time would be of great importance, especially if the material was more or less viscous. To make readjustment easy would require the whole interior body to be perfectly fluid and responsive to pressure, like water in a water-filled rubber ball when dented. It seems incredible that the interior of the earth can be in any such condition, and if it is not in such condition the difficulties of explaining resilience in this way are incalculably greater. The very vastness of the region affected appears to exclude this cause.

It is also a question whether both modes of depression can be postulated as occurring at once with the values stated, for Woodward's calculation of the effect of elastic compression is based on the assumption that the earth is solid to the center and highly rigid throughout—an idea that is hardly compatible with the postulate of a widespread fluid magma beneath the crust. If the interior is fluid, the elastic compression found by Woodward must reside solely in the rigid crust above the fluid interior. But, assuming for the moment that the two modes of depression can occur together with the values assumed, it becomes possible, on the basis of definite assumptions as to the thickness of the ice, to calculate roughly the amount of resilience which would arise from each of these causes on the removal of the ice weight. Thus, employing the values used by Lane, if the ice be supposed to be 1,250 feet thick, the amount of elastic resilience on its removal would be one-fifth, or about 250 feet. This, presumably, would be instantaneous; that is to say, it would follow the decrease of ice weight at the same rate, but the hydrostatic readjustment of the fluid magma would be much slower, depending upon the degree of viscosity. On this assumption of ice thickness, according to Lane, the hydrostatic relief would give an additional uplift amounting to one-third of the ice thickness, or about 400 feet. This would give a total uplift of about 650 feet. On account of its slowness, however, the hydrostatic relief may be still in progress and not yet fully satisfied.

THEORETICAL AND ACTUAL UPLIFT.

LAKE SUPERIOR REGION.

Lane applies his theory to the region of Lake Superior, where he supposes the Huron Mountains on the south side of the lake to have been barely overtopped by the ice at its greatest thickness. If it be granted for the moment that Lane's assumption on this point is true, the thickness of ice measured from the present water surface of Lake Superior is approximately in accord with the assumed thickness of 1,250 feet in the Lake Superior basin close north of these mountains. The amount of uplift on the Keweenaw Peninsula has been on the least estimate 500 or 600 feet and may have been more. On the assumption made, therefore, the results seem to accord fairly well with expectation.

But although it is true that the Huron Mountains were not covered by a great depth of ice, even at the maximum of the Wisconsin ice sheet, Lane's assumption that they were barely overtopped is at variance with evidence recently found by Mr. Leverett showing clearly that their highest parts were heavily scored by the ice sheet that passed over them. On the most conservative estimate the ice could hardly have been less than 1,500 feet thick and was in all probability 2,000 to 2,500 feet thick on the northern part of the high ground north and northwest of Champion, for at the maximum the ice moved nearly 150 miles southwest over this high region, nearly all of it more than 1,500 feet above sea level (900 feet above Lake Superior). Allowing for an average slope of only 10 feet to the mile for the surface of the ice back from the extreme front, the depth 150 miles back would be 1,500 feet, as stated above. But in all probability the average slope was nearer 20 feet to the mile, which would give a depth of 3,000 feet. The Keweenaw and Chippewa ice lobes merged on this highland and covered it completely,

the front of the ice advancing down to the northern side of the Driftless Area in Wisconsin. Over the middle of the outer part of Keweenaw Bay, say 20 miles directly south of Keweenaw Point, the ice surface must have been at least 500 or 600 feet higher than on the high ground north of Champion. Thus, by an estimate based on minimum values throughout, the depth of ice at the maximum of the Wisconsin sheet over the present surface of Lake Superior in the central part of Keweenaw Bay was 2,900 to 3,000 feet, or considerably more than twice the depth assumed by Lane. Applying to this depth of ice the ratios used by Lane, the amount of uplift due to elastic resilience would be nearly 600 feet and to this must be added that due to hydrostatic inflow amounting to nearly 1,000 feet, making a total uplift of 1,500 to 1,600 feet in Keweenaw Bay.

The total amount of uplift actually determined by observation near Calumet on the Keweenaw Peninsula is only a little over 500 feet, this amount being recorded in the Algonquin beach. To this may be added by inference 150 to 200 feet for the first period of uplift, which is recorded in the Michigan, Huron, and Erie basins, but which is not shown by the beaches of Lake Superior. The absence of such evidence in the Lake Superior basin is not, however, a safe reason for inferring that the early uplift did not affect that basin, because the basin lies well within the uplifted region and none of its old shore lines extend south of the Algonquin hinge line, or even near to it. Thus the total uplift, recorded and inferred, was 650 to 700 feet, agreeing closely with Lane's estimate on the assumptions which he made, but amounting to less than half that which would correspond to the revised estimate of the thickness of the ice.

The selection of the Lake Superior region, however, as a place for testing the hypotheses of elastic resilience and hydrostatic readjustment appears to be unfortunate, in the light of recent investigations. Studies by Leverett and Sardeson in 1910, the results of which were announced in a paper presented by Sardeson at the Minneapolis meeting of the American Association for the Advancement of Science, indicate that the region west and north of the west end of Lake Superior became free of ice in an early part of the Wisconsin stage of glaciation. It was open territory at the time the Keewatin ice field had its greatest eastward extent in northern Minnesota, for the Superior lobe at that time extended but little beyond the western end of the basin. The only glaciation which this region experienced in the Wisconsin stage seems to have been from a weak ice advance southward from the high country between the Superior and Winnipeg basins. At the height of the Wisconsin stage of glaciation this country seems to have had a covering of ice which was thin in comparison with that in the basins on either side, and before the earliest uplift recorded in the Huron-Erie basin it seems to have been free from ice. It is not yet known how far northeast this ice-free region extended, but it seems to widen toward the Canadian border. The existence of this area along the north side of the western part of the Lake Superior basin changes the glacial status of that whole region and puts the ice lobe of the western arm of Lake Superior into the category of strongly protruding marginal lobes, like the others farther south. The deep basin of the western arm of the lake was near the ice border toward the northwest as well as toward the south. And yet this whole region is well within the area of Algonquin uplift and both of the hinge lines shown in figure 14 (p. 503) pass far south of it.

ICE LOBES AND DRIFTLESS REENTRANTS.

If the problem be considered in connection with another differently situated ice lobe, a more certain and a very different light is thrown on the relations of uplift to ice weight. The best subject is the Great Lakes lobe. The base line of this lobe is 600 miles long and extends from the northeast angle of the Driftless Area in Wisconsin to the reentrant angle at Salamanca, N. Y. It happens that this base line is almost exactly coincident with the Algonquin hinge line in the Lake Huron basin. It lies only a few miles south of this line and has almost the same trend. Within the area of this lobe there is no evidence whatever of either depression or elevation of the land in Wisconsin glacial time before the movement which raised the land north of the first or Whittlesey hinge line. The whole lobe, therefore, the part north of the first hinge line alone excepted, lies within the area of horizontality, and as the base line of the lobe is substantially coincident with the Algonquin hinge line, it may be said that only that part of the

lobe which covered the area between the two hinge lines was affected by depression and resilience, and further, that the movements affecting it were all of the first period and had ceased before the beginning of Lake Algonquin. It may therefore be said that the whole lobe lies within the area of horizontality when considered with reference to the Algonquin period of elevation.

From the front of this great lobe back to its base line the surface of the ice sheet must have risen in the usual way. The data for determining the rate, however, are meager. The present land surface at both ends of the base line is something above 1,500 feet above sea level. Both of these points, however, were about 100 feet lower than now before the beginning of the first period of uplift. The rim of the Lake Erie basin rises gradually eastward from 760 feet above sea level at Fort Wayne, Ind., to above 1,000 feet across most of northern Ohio and to above 1,500 feet at Salamanca, N. Y. Northward from Fort Wayne the rim rises to over 1,000 feet above sea level in northeastern Indiana. The rim of the Lake Michigan basin rises from 590 feet at Chicago to over 1,000 feet above sea level in northeastern Indiana and gradually to 1,000 feet in southern Wisconsin and to over 1,500 feet at the northeast corner of the Driftless Area. The present surface of Lake Erie is 573 feet and of Lakes Huron and Michigan 581 feet above sea level.

The ice surface must also have risen along the base line from the two ends toward the middle as well as backward along the central axis from the apex. At an average of 10 feet per mile for 400 miles the surface would rise 4,000 feet from the apex to the base. This would allow for a rise of 2,000 to 2,500 feet in 300 miles from the ends of the base line to the middle. This average rate seems low enough. If the rise be divided into sections with a higher rate at the front diminishing toward the base any estimate that seems tenable leads to a rise of at least 4,000 feet. For example, if the rate averaged 50 feet per mile for the first 10 miles, 20 feet per mile for the next 90 miles, 10 feet per mile for 100 miles, and then 5 feet per mile for 200 miles, the total rise to the base line would be 4,300 feet. A rise of 4,000 feet in 400 miles on the central axis and of 2,000 to 2,500 feet in 300 miles on the transverse axis at the base line does not seem excessive—certainly not in comparison with the Greenland and Antarctic ice sheets as now known. Indeed, it is almost certainly an underestimate, rather than the reverse. This would mean a depth of ice of something near 4,000 feet over the head of Saginaw Bay and the south end of Lake Huron. In the Huron-Erie basin the Whittlesey hinge line lies about 75 miles south of the Algonquin hinge line, and the surface of the ice over Lake St. Clair and for 100 miles or more to the west along the former hinge line may be supposed to have been between 500 and 700 feet lower than at the base line. Even if the thickness of the ice on the middle of the base line was as little as 3,000 feet, this is equal to the thickness found by the revision of the estimate for Keweenaw Bay in Lake Superior and is more than twice the thickness which Lane found so closely accordant with his results for elastic resilience and hydrostatic readjustments in that region. He found that 1,250 feet of the ice there produced depression followed by 650 feet of resilience (combining both causes), but on the Whittlesey hinge line, 75 miles south of the base line of the Great Lakes lobe, there was probably fully 3,000 feet of ice, possibly even 4,000 feet, and yet there is no evidence whatever of either depression during ice occupancy or of resilience following its removal.

RELATION OF ICE WEIGHT AND HINGE LINES TO ICE MARGIN.

EFFECT OF DRIFTLESS AREAS.

In Wisconsin the first hinge line passes through the central part of the Driftless Area, which was at the time of the Wisconsin ice sheet simply a large reentrant angle, and it passes also across the central part of the driftless reentrant south of Salamanca. Neither of these areas was covered by the Wisconsin ice sheet at its maximum, nor were they covered by any of the earlier ice sheets. Yet the hinge lines keep their courses with scarcely any deviation across the Great Lakes ice lobe, the Driftless Area, and the Salamanca reentrant angle. Indeed, looking at the details a little more closely, it appears that the only place where the first hinge line is concave, even very slightly, toward the south is in the central part of the

Great Lakes lobe, 100 miles or more west of Lake St. Clair (see fig. 14), and that the only places, within the area here discussed, where the first hinge line is convex toward the south are in the Driftless Area of Wisconsin and the Salamanca reentrant angle. In the Great Lakes lobe the southward concavity of the line looks as though the uplifting forces had met some resistance there which had prevented them from reaching as far south as they otherwise would. On the contrary, the southward convexities in the Driftless Area and the Salamanca reentrant look as though the uplifting forces had found less resistance there and had reached a little farther south than the mean. The relations of these details certainly present problems of great difficulty for those who believe the uplifts to be due solely to depression by ice weight and resilience following its removal.

These facts and relations raise a number of important questions. What was the order of magnitude of the uplifting force? How much pressure and how large an area were required to produce the initial effect of depression? On the one hand, it was manifestly of such an order of magnitude that the weight of 3,000 or 4,000 feet of ice fell a trifle short of being critical; that is to say, it did not produce appreciable depression, for the removal of ice of that thickness did not produce resilience at the first hinge line, although at points a little farther north, where the ice was thicker, there was a slight uplift following removal of the ice. Yet the removal of less than this thickness of ice over the central part of the ice field north of the hinge line was apparently followed by relatively rapid uplift of 100 to 200 feet throughout a large part if not all of the region still covered by ice. In this movement the ice load then remaining was uplifted along with the land. On the best interpretation now available it is assumed that the removal of 3,000 or 4,000 feet of ice at the hinge line by melting and the retreat of the ice front, including the marginal belt with its relatively steep surface gradient, would be accompanied by a lowering of the central area of the ice field, not in like amount but in a considerably less amount, perhaps half as much or less. The surface gradient near the central area would be low, even if gravity were the only cause of the radial movement of the ice. If radial movement of snow by the action of powerful and permanent anticyclonic winds upon it before its consolidation into ice is an important factor, the surface gradient would be likely to be still lower.

On the assumption that the removal of the weight of the ice was the cause of the uplift, these considerations lead to the conclusion that at the hinge line the superposition of 3,000 or 4,000 feet of ice on the land did not add weight enough to start a movement of depression, not even by elastic compression, and consequently its removal was not followed by resilience, but that in the central part of the ice field the accumulation of 10,000 to 15,000 feet of ice did produce depression, and the subsequent removal of say 1,500 to 2,000 feet (considerably less than the maximum thickness at the hinge line) did cause resilience with resultant uplift. Whether such a conclusion is tenable or not in the light of known physical and dynamic laws is a problem for the geophysicist.

On the other hand, the first hinge line takes a direct course across driftless reentrants as well as across great ice lobes, as if the uplifting movement had had nothing whatever to do with such ice weight as affected the land under the basal part of the Great Lakes lobe. Apparently, a variation of surface load ranging from zero to the weight of 3,000 or 4,000 feet of ice was not enough to cause marked deviation in the hinge line. Indeed, the very slight deviation observed is in the wrong direction to have any significance with regard to ice weight. If ice weight produced depression it seems certain that it was confined chiefly to an area much farther north, where the ice was much thicker than at the base line of the Great Lakes lobe. In order to fit the facts, it seems necessary to suppose that marked depression by ice weight occurred only where the ice was two or three times as thick as at the base line. If, as seems probable, there was a large area of ice of great thickness farther north and northeast, strong depression may be supposed to have taken place there. It seems probable that the area of depression would not be limited by a sharp boundary with vertical sides or with a very steep gradient, for since the surface of the ice rose gradually from the edge back to the highest point, the amount of depression would diminish gradually from the central area out toward the ice margin. But it

might fall considerably short of reaching the extreme margin or even the mean line of the lobate margin. If depression depended on a central ice mass of great thickness and was not influenced by the relatively thin ice of the marginal part with its lobes, it might be expected that the outer boundary or hinge line of depression and of subsequent resilience would lie within the marginal belt of the ice field and would follow a straight or gently curved line substantially parallel with the isobases of the uplifted region to the north and largely if not entirely independent of the marginal lobes and reentrants. Thus, the elevation of the land for probably 100 to 150 miles north of the first hinge line was in all probability due not to depression by the weight of the ice that rested directly upon that land (at the maximum of the ice) but to the greater weight of the much thicker ice farther north, the depression under which died out gradually southward into the marginal area, where the weight of the thinner ice failed to produce depression.

As the retreat of the ice front progressed from the maximum boundary, the height of the entire ice surface to the north and hence the thickness of the ice and the weight with which it pressed upon the lands beneath it were reduced, and it was presumably this reduction of weight in the central, thickest part of the ice field that caused resilience, and not the uncovering of the marginal belt by the shrinkage of the lobes. In view of the independence of the hinge lines in relation to the irregularities of the ice margin it seems certain that only a small part, if any, of the uplift in the region discussed by Lane (Huron Mountains and Keweenaw Bay, Lake Superior) could have been caused by the removal of the weight of the ice mass of that immediate vicinity, and that the uplift, if due at all to the removal of ice weight, was due mainly or wholly to the removal of the much thicker ice farther north or northeast.

The area of marked depression under the central mass of the ice sheet may be regarded theoretically as a saucer-shaped basin, its outer margin sloping gently upward and dying out to a hinge line in the marginal belt, where the ice weight was not sufficient to produce depression. Questions arise here as to the probable breadth of the inclined rim of the depressed basin, the distance to which depression may have extended beyond the area of effective ice weight, and the size of the area that might be left bare of ice without markedly modifying the courses of the hinge lines and isobases.

The boundary of the light and short-lived glaciation around the west end of Lake Superior appears to widen toward the northeast in northeastern Minnesota, as though extending across into Canada. This it may do, and it may include a large part of the high region which lies north of the western arm of Lake Superior and west and northwest of Lake Nipigon. As may be seen on the relief map of the Dominion of Canada,[1] this area is occupied by a high plateau covering about 100,000 square miles. The widening toward this plateau indicates that it was not a region of strong glacial growth and dispersion and hence of thick ice, but that it was in the marginal belt and was covered, if at all, at the Wisconsin maximum only thinly and that for a relatively short time. If this area extends into Canada, as seems probable, it reaches so far back from the hinge line, as determined by the Lake Agassiz beaches in Minnesota, that it seems to call for too great a width of the propagated marginal belt of the ice-depressed basin.

Suppose a nunatak, or rather, a flat island in the ice field, like that which existed for a time in the southwestern peninsula of Ontario, surrounded by thick ice at some distance, but with the ice thinning toward it on all sides. If the island were of small area it is easy to believe that it would be carried down along with the depression of the surrounding heavily weighted lands, although it was itself not covered or only thinly covered, and that it would come up again when the ice disappeared and the surrounding lands were affected by resilience. How large such an island must be to be exempt from the influence of conditions directly affecting only the surrounding lands and not the island itself is a question. Even if the island itself be relatively small, 200 or 300 miles of relatively thin ice must be allowed for in the margin around it. The area in Canada exempt from direct depression by ice weight may have been larger than the whole of the high plateau; and, if so, the northernmost boundary of the nonweighted land would be at least 400 or 500 miles back from the hinge line at Traverse Lake, Minn. This region of light and short-

[1] White, James, Dictionary of altitudes in Canada, Ottawa, 1904, map.

lived glaciation, therefore, is set back so far into the area of uplift that if it is as large as seems likely (including the marginal belt of relatively thin ice) it seems to constitute a serious obstacle to the hypothesis of depression by ice weight.

The greatest amount of uplift yet recorded is that found by Coleman at Gondreau Lake, northeast of Lake Superior. Lake Kaministiquia, supposed by the writer to have been a local ice-dammed lake, seems likely from Mr. Leverett's recent results to be merely a bay of Lake Duluth, or possibly of Lake Algonquin,[1] with an upper limit more than 1,500 feet above sea level. These shore lines suggest that 900 to 1,000 feet of uplift has affected the northern part of the plateau referred to, and this inference will have to stand, unless facts are found that disprove it, which now seems decidedly unlikely, especially in view of Coleman's recent account of Lake Ojibway.[2] Coleman presents many facts relating mainly to high-level lake clays overlying the drift north of Height of Land between Lake Nipigon and Lake Abitibi and to terraces, belts of sand, and gravel at higher levels. He finds higher old water levels passing above the cols across Height of Land and regards them as temporary arms of Lake Algonquin reaching across to the Hudson Bay slope and covering narrow belts of this slope in front of the retreating ice sheet. They are not so high as the beach at Gondreau Lake, but they appear to mark levels not far below it, and though as yet they can not be positively proved to belong to Lake Algonquin, they indicate the great uplift suggested for the plateau west of Lake Nipigon. The plateau corresponds to the supposed island in the preceding discussion.

These old lake levels are several hundred feet above the upper limit of marine submergence (about 450 feet above Hudson Bay) as marked by beds of fossil marine shells farther north on the same slope. The fossil-shell beds could not have been deposited until after the ice sheet had disappeared from the region where they are found, and the movement by which they were elevated consequently came still later. The withdrawal of the ice from the southwest slope of the James Bay basin could hardly have been earlier than the later stages of Lake Algonquin and was probably considerably later. Yet, if the plane of the Nipissing beach in the northern part of the upper lake region be produced northward to the shell bed on Albany River, it would indicate an uplift of only 200 to 250 feet. This suggests that the shells may have been raised 150 to 200 feet before the uplift recorded in the Nipissing beach. The data are still too few to permit final conclusions, but they seem thus far to be in accord with the conclusions reached from the study of the Great Lakes.

SHIFTING OF THE HINGE LINE.

For such difficulties as these, which seem strongly unfavorable to resilience following depression by ice weight, the northward shifting of the hinge line and the time relations of the uplifting movements to the retreat of the ice seem to be partial if not equal offsets. The ice front rested close north of the line WW (fig. 14, p. 503) when the first period of uplift began, and the hinge line shifted almost to the Algonquin hinge while the ice retreated to the position AA.

The northward shifting of the hinge line during the retreat of the ice is shown diagrammatically in figure 15 (p. 505), the positions of the lines being only roughly determined. The movements appear to have been spasmodic, and they cover altogether the retreat of the ice from the late phase of Lake Maumee, not far from the time of the Yale moraine, nearly to the time of the Port Elgin moraine (AA, fig. 14). The Warren hinge line is 15 to 17 miles north of the Whittlesey hinge line, the Grassmere and Lundy about 40 miles north of the Warren, and the Algonquin 15 to 17 miles north of the Grassmere and Lundy. A more pronounced rise begins about 40 miles north of the Algonquin line and appears to correspond to the time of the Battlefield beaches, when the rate of uplift was most rapid.

The retreat of the ice front from the extreme limit to the line WW was synchronous with the lowering of the entire ice surface in the north by probably 1,500 to 2,000 feet, and this much ice removed from the top of the sheet where it was probably at least 10,000 to 15,000 feet thick

[1] Notes on the abandoned beaches of the north coast of Lake Superior: Am. Geologist, vol. 20, 1897, pp. 117-119.

[2] Coleman, A. P., Lake Ojibway, the last of the great glacial lakes: Eighteenth Ann. Rept. Bur. Mines, Ontario, 1909, pp. 284-293, particularly pp. 286-287.

may be supposed to have reduced the ice weight and inaugurated the uplifting movement. Later, when the ice front had retreated 150 to 200 miles farther, and another ice layer probably 1,000 feet or more in thickness had been removed, the great Algonquin uplift began. This, again, continued while the ice retreated 150 miles farther, and after a second pause during the time of the Nipissing Great Lakes, the uplift was resumed and has continued to or nearly to the present time. The natural significance of such relations as these seems suggestive and strongly favors resilience following depression by ice weight. Still, the adverse factors mentioned above appear to be of equal or greater strength.

ABSENCE OF RECENT FAULTS.

Another thing that seems strongly favorable to the hypothesis of depression by ice weight is the fact that only a few very small step faults have been found in all the region recently uplifted. The greater number of the faults so far observed run north and south in New York and Vermont east of Hudson River.[1] Others have been found in Nova Scotia and elsewhere. Small anticlinal folds of recent date are common in the shale around the western end of Lake Ontario. Depression by ice weight would be unlikely to produce faults, because the movement would take place beneath the heavy ice load, which would be in its effects equivalent to the overlying load of strata that contributed to some of the strongly folded parts of the Appalachian Mountains, where folding is conspicuous and faults rare. Resilience following the removal of the ice would also be unlikely to produce faults, because much of it occurred beneath considerable thickness of ice, because the upward force was widely and evenly spread over a great area and was lacking in concentration at any particular place or along any particular line, and because the forces both of depression and resilience increased with extreme slowness. The phenomena of the uplifted region seem as a whole distinct and different in kind from those that would be expected as normal results of the usual processes of mountain making and continental growth. Still, it is not certain that faulting need be strong in the initial stages of folding in mountain making.

PRE-WISCONSIN DEPRESSION AND RESILIENCE.

The question naturally arises whether any evidence exists of depression and resilience in the older glacial and interglacial epochs.

A few phenomena, such as the interglacial lake beds and the buried old land surfaces at Toronto, suggest episodes of pre-Wisconsin glacial and lake history closely resembling some of those associated with the Wisconsin ice sheet and the lakes of its waning phase. It seems certain that if the basin of Lake Ontario in pre-Wisconsin interglacial times had been continuously as much depressed with reference to sea level as it was at the maximum of the Wisconsin glaciation there could have been no lake beds nor any old land surfaces where those at Toronto have been found, but only glacial and marine beds.

RELATION OF ISOBASES TO THE PRE-CAMBRIAN BOUNDARY.

The partial parallelism of the isobases to the pre-Cambrian boundary is interesting and probably deeply significant, but its meaning is not yet clear. De Geer[2] found that the isobases of the uplifted marine shore lines in Sweden maintain a close parallelism with the boundary of the pre-Cambrian rocks, conforming even to relatively small details of that boundary. In the region of the Great Lakes the isobases appear to have the same parallelism to the pre-Cambrian boundary (line RR, fig. 14, p. 503) from the southeast end of Lake Superior to the east end of Lake Ontario, running in a nearly straight line between these points. The relations to minor details have not yet been fully worked out, but so far as observed the parallelism does not appear to be so close as in Sweden. Outside of the interval mentioned the isobases appear to show only a very general

[1] Woodworth, J. B., Postglacial faults of eastern New York: Bull. New York State Mus. No. 107, 1907, pp. 5–28.

[2] De Geer, Gerard, Quaternary changes of level in Scandinavia: Bull. Geol. Soc. America, vol. 3, 1892, pp. 65–66; also, On Pleistocene changes of level in eastern North America: Proc. Boston Soc. Nat. Hist., vol. 25, 1892, pp. 454–477. The important passages are quoted by Goldthwait in Bull. Geol. Soc. America, vol. 21, 1910, pp. 245–246.

tendency to parallel the Azoic boundary. Near this boundary, however, as pointed out some years ago by Chalmers,[1] the northward rise abruptly increases. Whether this is merely an expression of differential effects of elasticity or of slight effects of overthrusting or underthrusting or of some other cause has not been determined. The existence of this increased rise has recently been verified by Goldthwait, Johnston, and the writer near Kirkfield and Orillia, Ontario,[2] and by Mr. Leverett on St. Joseph Island.[3]

EUSTATIC AND OSCILLATORY MOVEMENTS.

Eustatic and oscillatory movements, such as have been described by Suess, are of little import in the present discussion, for neither principle appears to have acted perceptibly in the Great Lakes region. The land in the area of horizontality appears to have been a "steady mass," remaining unmoved throughout the elevation of the lands to the north. It is not improbable, however, that both of these kinds of deformation have been operative to a slight but recognizable degree along the borders of the continent, where the shore lines of the sea were involved. If such effects have operated there they must also have acted in the region of the Great Lakes at the same time and in the same direction, but they appear to have been too small in amount to be detected.

TECTONIC EARTH MOVEMENTS.

WIDE RANGE OF PHENOMENA.

Although the hypothesis of resilience following depression by ice weight appears to have much strength, perhaps this strength seems greater than it really is, because the phenomena contemplated are confined to a somewhat restricted field. Beyond the region of the Great Lakes a vast stretch of the earth's surface, comprising almost the whole of northeastern North America, including Hudson Bay and all the lands for 400 to 500 miles around it and reaching from New England and Labrador on the southeast to the Arctic Ocean and Bering Sea on the northwest, was affected at the same time and in the same way as the Great Lakes region. The very vastness of this area operates to exclude certain hypotheses that have been suggested. The limitations which it imposes seem particularly applicable to all hypotheses that depend on the transfer of subcrustal molten magmas, unless the modern conception of an essentially solid, rigid interior for the earth is wrong, and the old idea of a molten, highly fluid, essentially nonviscous interior, moving under hydrostatic laws, is right. The writer is disposed to accept the newer view. But this would exclude the transfer of molten magmas as a cause of resilience and place the whole burden on elasticity, which is calculated to account at most for less than two-fifths of the total uplift. Moreover, the failure of the uplifts to act instantaneously or pari passu with the removal of ice weight casts a further doubt upon the relation of the uplifts to elasticity.

In the present unsettled state of knowledge concerning the ultimate fundamental principles of geology, and especially of the primary forces involved in dynamic geology, it is not possible to specify with certainty how and in what particular manner the old shore lines may have been deformed by geotectonic processes. Geologists have so long been accustomed to speak of "upheavals" and "subsidences," without having any definite or adequate conception of the cause of such movements, except so far as based on vague ideas of cooling and contraction of a molten globe, that explanations by the use of these terms are indefinite and of comparatively little value. Even now there is no generally accepted explanation of the growth or formation of continents by dynamic processes, and hence there is no genetic classification of the characteristic features of continents. Substantial progress along the lines of any contraction hypothesis seems unlikely, and real progress seems more likely, at least in the opinion of the writer, along two or three of the newer lines of thought, probably by a combination and modification

[1] Chalmers, R., The geomorphic origin and development of the raised shore lines of the St. Lawrence Valley and Great Lakes: Am. Jour. Sci., 4th ser., vol. 18, 1904, p. 175.

[2] Summary Rept. Canadian Geol. Survey for 1909, 1910, p. 104.

[3] Personal communication, 1912.

of the planetesimal hypothesis of Chamberlin and that of continental crustal creep with peripheral folding as formulated by Suess.

CRUSTAL CREEP.

The greatest earth movements involved in the formation of continents and mountains are mainly horizontal or tangential creeping and thrusting movements, the associated movements of elevation and subsidence being mainly incidental or secondary. Hence deformations due to tangential or nearly horizontal creeping movements, such as Suess found to be involved in the formation of the mountain ranges of Asia and in the growth of the continent itself, are fully competent to be the cause of elevation and warping of old shore lines.

The writer has endeavored to apply to North America the principles evolved by Suess in Asia [1] and has found two widely separated sets of phenomena that clearly indicate a crustal movement of the continent toward the southwest. One of these is the mountain knot of Alaska, the highest mountain mass in North America, located at the angle where the Aleutian and Cordilleran mountain ranges come together on converging lines. The mountain ranges and the knot are mainly of Tertiary age. The other feature is the rift valley on the northwest and west sides of Greenland, probably mainly of Tertiary age also. The bearing of these two features on the direction of crustal movement of the continent is clear and single in its meaning and is not susceptible to two opposite interpretations. In this respect they stand in strong contrast with the usual explanations of overthrusts and folds, and even a group of folds showing diminishing intensity from one side to the other, which are nearly always susceptible to two opposite interpretations as to the direction of the main deep-seated folding force. This arises from the difficulty of distinguishing relative from actual movements. In the Rocky Mountain region what have generally been called northeastward overthrusts may just as truly be described as southwestward underthrusts with northeastward overthrusts as secondary results. Suess found the most intense folding at the front of the southward creeping crustal sheet in Asia, where this sheet met a resistant obstacle—either a foreign mass, like India, or more often the upturned, metamorphosed, basal layers of the crustal sheet itself. On the other hand, the mountain knot of Alaska and the Greenland rifts are neither of them open to two opposite interpretations; they are facts of two different classes and relate to distant and opposite sides of the continental sheet, and yet they indicate the same direction of crustal creep. It is perhaps worth while to point out that the recently uplifted and tilted region of the Great Lakes and the extension of this deformed region to the northwest across the continent follows a course substantially parallel with the great disjunctive line or rift on the west side of Greenland and is also in part subparallel with the Tertiary mountain belt of the Pacific coast. All of the region east of this belt has been affected by the same recent uplifting movement, and its southwestern border, passing through the Great Lakes region and far to the northwest, appears to stand either in the relation of a broad, low swell or anticline or else a broad, low monocline with gentle dip to the southwest. It occupies a medial position between the Greenland rift and the Cordilleran range, and its axis is transverse to the direction of the southwestward crustal creep which these two features indicate. Its position is therefore natural for a fold produced by crustal movement in the direction indicated, and such movement seems to the writer to be the only one that would explain the uplift as part of a definite, systematic process of continental development.

The recurving of the marine isobases south and east of Quebec (fig. 14) suggests that a broad, low anticlinal fold is there pitching downward to the east. This may or may not be true, for, as was pointed out above, the raised beaches near Quebec probably do not record all of the recent uplift in that region, and the complete record might show a different configuration of the isobases. But from the eastern end of Lake Ontario the isobases run west-northwest at least to some point beyond Manitoba, and if an anticlinal fold exists its axis lies, in all probability, north of the Great Lakes and parallel with the isobases now determined. A broad belt west and northwest of Hudson Bay, including the region of the Archean rocks and

[1] Bearing of the Tertiary mountain belt upon the origin of the earth's plan: Bull. Geol. Soc. America, vol. 21, No. 2, 1910, pp. 179–226.

the chain of lakes along the Paleozoic margin, and extending from the Arctic Ocean through Alaska to Bering Sea, has been elevated 300 to 400 feet out of the sea since the disappearance of the last ice sheet. It is perhaps somewhat significant that in Alaska this belt includes a large region which has not been glaciated, and hence where direct depression by ice weight did not occur. No great ice sheet was near to that region.

If the crustal creeping movement of Tertiary time had not entirely ceased at the time of the glacial period it is easy to see that a slight crustal movement toward the southwest might be the cause of the observed uplifting and tilting. It would not require much horizontal movement of a crustal sheet 5 to 10 miles thick to produce the relatively slight arching recorded in the beaches. It may well be that the ice sheet influenced this movement to some extent and contributed in some degree to the determination of its place and limits, although it is at present hard to see just what effect it would have and how it would act. The general course of the margin of the uplifted belt is broadly parallel with the limits of the crystalline rocks for a great distance but appears to turn away westward across Alaska to the Bering Sea. Even if the uplifted belt is some sort of fold or upswelling produced by recent crustal creep from the northeast, it is not possible to say at present to what extent, if any, ice weight and geologic structure may have influenced the result.

Orogenic movements of no small amount have occurred in the region of the Cordilleran mountain belt within the Quaternary period, and these seem to imply a continuance, at least in some slight degree, of the creeping movement of the continental crustal sheet.

CONCLUSIONS.

Although the uplifts were spasmodic in character, the time relations are so intimate that it is hard to resist the impression that the land rose simply because the ice and its weight disappeared. And yet there is no reason why tectonic movements in the earth's crust may not have occurred with just these time and place relations to the retreating ice sheet. Perhaps the truth lies in a middle course and both causes may have contributed to the result. If the uplifting movements were to any large extent tectonic or epeirogenic and independent of resilience after depression by ice weight, then the undeviating course of the hinge line across large ice lobes and unglaciated reentrants is not a matter of surprise nor of special difficulty.

However, it is not intended here to attempt to reach final conclusions as to the cause of the uplifts but merely to point out some of the limitations established by the known facts. Ice weight may have been an important contributory factor in the great Quaternary regional uplifts but probably did not have the values nor act in the simple and complete way supposed by many. The limitations seem to carry the problem suggestively near to the realm of another class of earth movements due to entirely different causes.

There appears to be no reason to question the validity of Woodward's result in his determination of the elastic compressibility of the earth, nor of Lane's quantitative application of the same to the concrete case assumed by him. But the facts fall so far short of agreeing with these theories that the whole matter becomes uncertain.

In conclusion it may be said that while the preponderance of evidence may appear at the present time to be slightly in favor of resilience following depression by ice weight as the main cause of the uplifting of the land and the deformation of the shore lines in the region of the Great Lakes, the difficulties in the way of a complete demonstration of this as the main cause seem well-nigh insuperable. It seems certain that some new basis of physical principles better adapted to a quantitative analysis of the problem will have to be found before the ice-weight hypothesis can be firmly established.

Standing as a close second to the hypothesis of deformation by ice weight is that of deformation by uplifts of the land incidental to crustal creeping movements, which are simply the latest or most recent impulses in a process of continental growth reaching back into Tertiary time. Both causes may have acted, but if certain evidences which are now supposed to indicate relatively recent crustal creep toward the southwest are substantiated by future investigations the hypothesis of resilience following depression by ice weight seems likely to become of secondary importance.

CHAPTER XXVI.

ECONOMIC RESOURCES.

By Frank Leverett.

Only deposits of economic value connected with or developed upon the formations which form the theme of this monograph are discussed in this chapter, and as special reports have been published by this Survey and by the State surveys on the more important of these economic resources, the discussion aims merely to direct attention to these reports and to set forth in a very general way the relations of the resources to the glacial formations.

ERRATICS IN THE DRIFT.

In the drift are incorporated metals and ores such as copper, iron, and gold, precious gems like the diamond, and blocks of coal, whose sources are in the rock formations passed over by the ice sheet. (See pp. 64, 249.) All these are so rare and so irregularly distributed that they can not be profitably worked on any commercial scale, but are to be classed as "finds." Gold washing has, it is true, been attempted at a number of places in Indiana and neighboring States, but has scarcely ever yielded a fair day's wage and can be said to pay only when the miners have leisure time to spend. Before the character and origin of the glacial deposits were understood the finding of these metals and gems led to erroneous conclusions as to their occurrence in paying quantities in the near vicinity, and conclusions of this sort are drawn nowadays by many uninformed persons.

In some localities, where the rock formations are completely covered, the glacial deposits contain sufficient amounts of certain kinds of building stone in the form of bowlders to constitute a valuable economic resource, which, though becoming scarce in many localities, will not be exhausted for some time. Such stone is especially plentiful along most of the moraines. In other places masses of limestone have been so abundant in the drift or on its surface that they have supplied limekilns for years and have been very useful, especially in the early days of settlement.

MARL OR BOG LIME.

Marl deposits of great depth, sufficient to warrant the erection of large cement mills, exist on the borders of many lakes of Indiana and Michigan. These deposits were drawn on by early settlers for lime and to some extent for land plaster. Their use was so extensive and their value so great that in the earliest surveys of both States data were collected as to their distribution. It was not, however, until they began to be used on a large scale in the manufacture of Portland cement that special reports on them were prepared. In Indiana the State Geological Survey has made systematic investigation of nearly all the lakes and basins which formerly held lakes but are now filled with marl and peat. The published report sets forth not only the extent of workable but also of what are classed as unworkable deposits, the latter term being applied where the quantity seems insufficient to justify the erection of a cement mill.

In Michigan the investigations have been less complete. The field, however, is much more extensive than in Indiana, for marl lakes are scattered over the whole of Michigan and they occupy only a small area in the northern part of Indiana. The mills for the manufacture of Portland cement in Michigan, however, are nearly all located in the populous southern part, where a strong demand for the product exists, where transportation facilities are good, and where the clay or shale needed in the manufacture of cement can be had within convenient distances.

Since cement making became an important business, reports on the production of cement in the United States have been published annually by the United States Geological Survey in Mineral Resources. These papers are largely statistical and are based on correspondence rather than on field investigations. Several important special reports and papers dealing with the origin, distribution, and utilization of the marl of Michigan and Indiana have also been published, as follows:

Blatchley, W. S., and Ashley, G. H., The lakes of northern Indiana and their associated marl deposits: Twenty-fifth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1901, pp. 31-321.

Blatchley, W. S., Cement resources: Thirty-first Ann. Rept. Indiana Dept. Geology and Nat. Res., 1906, pp. 50-61.

Davis, C. A., A contribution to the natural history of marl: Jour. Geology, vol. 8, 1900, pp. 485-497; vol. 9, 1901, pp. 491-506; Michigan Geol. Survey, vol. 8, pt. 3, 1903, pp. 65-96.

——— A remarkable marl lake: Jour. Geology, vol. 8, 1909, pp. 498-503.

Fall, Delos, Marls and clays in Michigan: Michigan Miner, vol. 3, 1901, No. 11, pp. 11-14; Michigan Geol. Survey, vol. 8, pt. 3, 1903, pp. 343-353.

Hale, D. J., and others, Marl (bog lime) and its application to the manufacture of Portland cement: Michigan Geol. Survey, vol. 8, pt. 3, 1903, 386 pp.

Russell, I. C., The Portland cement industry in Michigan: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, pp. 629-685.

——— Marl or bog lime: Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1908, pp. 12-13.

PEAT.

Peat is very extensive in northern Indiana and in Michigan on the borders of lakes and in poorly drained situations. It has been made a subject of special investigation by Charles A. Davis [1] and by Arthur E. Taylor.[2] Taylor's report contains the results of numerous borings in a large number of extensive peat bogs of northern Indiana, and includes maps showing the extent of the bogs and their situation in reference to railway transportation lines. Davis's report contains fewer data concerning the thickness of peat in the bogs of Michigan but goes more fully into the origin and the ecology of peat. He discusses also the use of peat as fuel, arguing that though peat is unlikely to be utilized to more than a slight extent in competition with coal, peat bogs will yield quick and sure returns if they are developed in a small way for local markets rather than on a large scale in competition with better-known and more widely used fuels. "A relatively small bog, a small investment, and a local market, with a limited requirement in quantity should make a combination which should be satisfactory to the owner and the investor, who could then afford to give his customers a fair price, which should run considerably below that paid for ordinary fuel, and still give good profits." Davis's report also describes peat-working machinery in considerable detail.

In addition to these two large reports Taylor[3] and Davis[4] have each published short papers on this subject.

CLAY.

The extensive till sheets of Indiana and Michigan are utilized to some extent for brick and tile, but are in most places too full of stony and sandy material to be suitable even for these products. The clay of chief commercial value in these States is a water deposit laid down either in lakes or in slack drainage. Loess deposits laid down by wind are important in southern Indiana, where also much of the alluvial material, being derived by wash from bordering loess, is suitable for use in some of the clay industries.

The thickest deposits of clay on the beds of the great glacial lakes are found in depressions protected against disturbance by waves. Thus in the Erie-Maumee basin deposits are thick in the area covered by Defiance Bay of Lake Whittlesey west of the Defiance moraine, and are very light on the submerged portion of the moraine and the plain to the east. The deposits become thicker, however, west of Napoleon and near Toledo and are drawn upon extensively for use in clay industries and for the manufacture of Portland cement. In the Rouge River basin west of

[1] Ann. Rept. Michigan Geol. Survey for 1906, 1907, 302 pp.
[2] Thirty-first Ann. Rept. Indiana Dept. Geol. and Nat. Res., 1906, 225 pp.
[3] Indiana peat, its origin and value: Jour. Am. Peat Soc., vol. 2, 1909, pp. 30-33, 64-67.
[4] Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1908, pp. 12-13.

Detroit, in a small area that stands a little lower than the Detroit interlobate moraine, lake clays are thick and furnish material for extensive brick works. In the Saginaw basin extensive deposits of nearly pebbleless clay exist but are not drawn upon for commercial use so much as the shales of that region. They are largely covered by sand deposits, so that their extent is greater than might be inferred from surface exposures.

On the borders of the Michigan basin lake clays are scarce, the eastern shore being prevailingly sandy. At the south end of the basin, however, from the vicinity of Michigan City to Hobart, Ind., some deposits of sufficient depth to be of commercial value are found. In the Grand Traverse region in Michigan, in Antrim and Grand Traverse counties, extensive deposits of clay or silt underlying the surface till have been utilized to some extent for brick manufacture, for which they are much more suitable than the overlying till sheet. They promise to be a valuable resource and are accessible with very little stripping on the bluff-like borders of the lowlands and lakes of the region.

West of Rensselaer, Ind., in the Iroquois basin, which was covered by a small glacial lake, lie silt deposits of considerable depth. These deposits are utilized by a brick plant at Brook, Ind.

Many valleys formerly occupied by pools held in place by ice dams are filled to great depth by silt deposits. Several such valleys are found in southwestern Indiana in Gibson, Pike, Vanderburg, and Posey counties.

In northwestern Indiana and southwestern Michigan, in many lines of drainage which were obstructed by the Lake Michigan glacial lobe, silt deposits underlie the surface sands. Deposits of this sort have been utilized in the clay industries at South Bend for more than 50 years. As far back as 1859 [1] extensive explorations were made to test the thickness of the clay.

As the value of the clay for use in the industries depends on its freedom from objectional ingredients and properties no statements concerning the importance of particular deposits can be made. However, clay having but little stony material is found extensively, and no doubt much of it will prove to have high commercial value.

The clay deposits and clay industries of northwestern Indiana have been made the subject of a special paper by Blatchley,[2] and the shales and clays of Michigan have been briefly discussed by Ries.[3] On the whole, however, this resource, so far as these two States are concerned, seems to have received scanty treatment in geologic literature.

SAND AND GRAVEL.

The many uses to which sand and gravel are put in the building trades and in road construction are making them a resource of far greater importance than was dreamed of a few years ago. Even the drifting dune sand on the shores of Lake Michigan is being used in the manufacture of sand brick and is shipped by the train load to Chicago for use in masonry. The gravel hills, which a few years ago were considered useless by the farmer, are now in demand for road material at a price per acre far above that of other farm land.

The roads and road materials of Indiana are the subject of a report of more than 1,000 pages,[4] much of which deals with the occurrence of gravel and the use already made of it. It is shown that throughout the area covered by the Wisconsin drift in Indiana suitable material for road building is so widely distributed as to obviate all long hauls. Hundreds of miles of gravel road have already been constructed. In southern Indiana some of the lines of glacial drainage furnish extensive gravel deposits suitable for road building, but a more widespread source for that part of the State is found in the rock formations, especially the limestone.

In Michigan, sand and gravel are easily accessible in nearly all parts of the State. In some of the more sandy parts the sand is so light as to render the roads difficult to travel, and it has been found expedient to stiffen the roadbed with a coating of clay. Gravel is less widely distributed than sand, and broad areas in the Saginaw basin and on the lake plains in the southeastern

[1] Indiana Geol. Survey, 1860, p. 200.
[2] Blatchley, W. S., Twenty-second Ann. Rept. Indiana Dept. Geology and Nat. Res., 1897, pp. 105-153.
[3] Ries, Heinrich, Michigan Geol. Survey, vol. 8, pt. 1, 1900, pp. 1-66, especially pp. 48-62.
[4] Thirtieth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1906, pp. 17-1057.

part of the State are inadequately supplied. Railroad facilities are, however, so good in these districts that road material is easily brought in. The additional cost of running a gravel train a few extra miles is a smaller item than the loading and unloading of the cars.

As yet no special report on the gravel and sand deposits of Michigan has been attempted, but many details as to their distribution may be obtained from the Pleistocene map of the southern peninsula issued in the reports by the Michigan Geological Survey for 1907 and 1912.

UNDERGROUND WATERS.

Underground waters from the glacial formations are generally abundant and are drawn upon not only for farm use but also for public supplies in a large number of villages and small cities in Indiana and Michigan. Several reports on these supplies have been issued by the United States Geological Survey and incidental mention has been made in the several county reports of the Indiana and Michigan geological surveys.

Contamination of underground water is very rare in these States. Only isolated cases have come to notice, most of them being in rural districts where pollution might easily have been avoided by a better selection of the well site or of the place for dumping slops and refuse.

The following list embraces the special reports issued on the underground waters of these States. They pertain in part to waters from rock formations but are chiefly devoted to those from the Pleistocene formations.

Blatchley, W. S., The mineral waters of Indiana: Twenty-sixth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1903, pp. 11–158.

Lane, A. C., Geology of Lower Michigan with reference to deep borings: Michigan Geol. Survey, vol. 5, pt. 2, 1895, pp. 40–87.

——— Water resources of the Lower Peninsula of Michigan: Water-Supply Paper U. S. Geol. Survey No. 30, 1899, 97 pp.

——— Lower Michigan mineral waters: Water-Supply Paper U. S. Geol. Survey No. 31, 1899, 97 pp.

——— Deep wells and prospects for oil and gas: Ann. Rept. Michigan Geol. Survey for 1901, pp. 65–75, 211–237.

——— Underground waters of lower Michigan: Water-Supply Paper U. S. Geol. Survey No. 114, 1905, pp. 242–247.

——— Many of the records published in Water-Supply Papers Nos. 182 and 183 were contributed by Lane from records in the office of the State geologist. Two special papers contributed by him deal with the water supplies of Lansing and vicinity (Water-Supply Paper No. 182, pp. 170–175) and with Huron County (Water-Supply Paper No. 183, pp. 257–268).

Leverett, Frank, Water resources of Indiana and Ohio: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1897, pp. 425–559 (especially pp. 474–482, 487–493, 495–501, 511–522, 527–531, 537–544).

——— Wells of northern Indiana: Water-Supply Paper U. S. Geol. Survey No. 21, 1899, 82 pp.

——— Wells of southern Indiana: Water-Supply Paper U. S. Geol. Survey No. 26, 1899, 64 pp.

——— Geological conditions of municipal and institutional water supplies in Michigan: Eighth Ann. Rept. Michigan Acad. Sci., 1906, pp. 99–110.

——— and others. Flowing wells and municipal water supplies of the southern peninsula of Michigan: Water-Supply Papers U. S. Geol. Survey Nos. 182 and 183, 1907. Contributions by Isaiah Bowman, W. F. Cooper, C. A. Davis, W. M. Gregory, M. L. Fuller, A. C. Lane, C. D. McLouth, J. F. Nellist, W. H. Sherzer, and J. A. Udden.

Russell, I. C., and Leverett, Frank, Underground waters: Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1908, pp. 14–15.

Vaughan, V. C., Michigan water supplies: Eighth Ann. Rept. Michigan Acad. Sci., 1906, pp. 111–118.

SOILS.

Close correspondence between glacial formations and the several kinds of soil developed on them is natural, and the glacial maps (Pls. VI and VII, in pocket) will serve to some degree as soil maps. The surface-geology map issued by the Michigan Geological Survey in the annual report for 1907 has on its legend not only glacial terms but also terms used by the Bureau of Soils of the United States Department of Agriculture for the sands, gravels, and clays of the southern peninsula of Michigan. It is questionable, however, if there was warrant for this definite application of the terms used by the Bureau of Soils, except in the particular districts covered by the soil mapping of that bureau. The classifications made by the Bureau of Soils are much more complex than the glacial classifications, in some places differentiating several grades of soil on a single kind of glacial formation on account of slight differences in color or in texture, or in coarseness of grain.

The mapping by the Bureau of Soils has been done in scattered areas of small extent. The following is the complete list of the maps published to October 31, 1914:

Soil maps of Indiana and Michigan.

Indiana.		Michigan.	
Allen County.	Marshall County.	Allegan County.	Pontiac area.
Boone County.	Montgomery County.	Alma area.	Saginaw area.
Boonville area.	Newton County.	Cass County.	Wexford County.
Greene County.	Posey County.	Genesee County.	
Hamilton County.	Scott County.	Munising area.	
Madison County.	Tippecanoe County.	Owosso area.	
Marion County.	Tipton County.	Oxford area.	

The mapping has been so distributed in Indiana and Michigan as to embrace nearly every class of glacial, fluvial, and lacustral formation. Thus in Michigan the Oxford and Pontiac areas represent the complex features of an interlobate district with associated gravelly and sandy outwash. The Saginaw area is wholly in a glacial lake bottom where characteristic lake clays and lake sands are found. The Alma and Pontiac areas are partly on lake bottom, partly on moraines and their associated till plains, and partly on fluvioglacial drainage lines. The Allegan area illustrates the combination of sandy plains and gravelly or loose-textured moraines found on the east side of the Lake Michigan basin. In Indiana, Allen County embraces a lake plain as well as moraines and till plains. Madison, Marion, Newton, and Tippecanoe counties are largely a till plain, though Newton County embraces also an extensive sand plain bordering the Kankakee. Greene, Posey, and Scott counties embrace loess-covered glacial formations and also unglaciated loess-covered districts (see Pl. VI), and the Boonville area lies entirely in an unglaciated loess-covered district.

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